Human Anatomy

HUMAN ANATOMY

INCLUDING STRUCTURE AND DEVELOPMENT

AND

PRACTICAL CONSIDERATIONS

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THE NERVOUS SYSTEM.

THE nervous system—the complex apparatus by which the organism is brought into relation with its surroundings and by which its various parts are united into one coördinated whole—consists essentially of structural units, the *neurones*, held together by a special sustentacular tissue, the *neuroglia*, assisted by ingrowths of connective tissue from the investing membrane, the pia mater.

The **neurone,** the morphological unit of the nervous system, includes a nucleated protoplasmic accumulation, the *cell-body*, and the *processes*. The former, usually spoken of as the *nerve-cell*, presides over the nutrition of the neurone and is the seat of the subtle changes giving rise to nervous impulse. The processes arise as outgrowths from the cell-body and provide the paths along which impulses are conveyed. They are very variable in length, some extending only a fraction of a millimeter beyond the cell-body, while others continue for many centimeters to distant parts of the body. The longer processes, which usually acquire protecting sheaths, are known as the *nerve-fibres*, and these, associated in bundles, constitute the *nerve-trunks* that pass to the muscles and various other organs.

Reduced to its simplest terms, the nervous system consists of the two parts represented in the accompanying diagram (Fig. 834). The one the *sensory neurone*, (*A*) takes up the stimulus received upon the integument or other sensory surface and, by means of its process (nerve-fibre), conveys such impulse from the periphery towards the central aggregations of nerve-cells that commonly lie in the vicinity of the body-axis. Functionally, such a path constitutes a *centripetal* or *afferent fibre* (*a*). The impressions thus carried are transferred to the second element, the *motor neurone* (*B*), which in response sends out the impulse originating within the cell-body (nerve-cell) along the process known as the *centrifugal* or *efferent fibre* (*e*), to the muscle-cell and causes contraction. The simple relations of the foregoing apparatus are, in fact, superceded by much greater complexity in consequence of the introduction of additional neurones by which the afferent impressions are distributed to nerve-cells situated not only in the immediate vicinity of the first neurone, but at different and often distant levels.

FIG. 834.

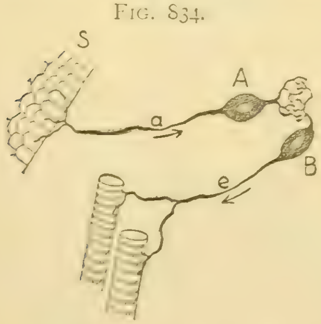


Diagram showing fundamental units of nervous system. *A*, sensory neurone, conducting afferent impulses by its process (*a*) from periphery (*S*); *B*, motor neurone sending efferent impulses by its process (*e*) to muscle.

Although very exceptionally the relation between the neurones may perhaps be that of actual continuity in consequence of a secondary union of their processes (Held), the view concerning the constitution of the nervous system most worthy of confidence, notwithstanding the bitter attacks by certain histologists, regards the neurones as separate and distinct units. While chained together to form the various paths of conduction, they are probably seldom, if ever, actually united to one another but only intimately related, since their processes, although in close contact, are not directly continuous,—contiguity but not continuity being the ordinary relation.

During the evolution of the nervous system from the simpler type, the cell-bodies of the neurones forsake their primary superficial position and recede from the periphery. In vertebrates this recession is expressed in the axial accumulation of cell-bodies either within the wall or in the immediate vicinity of the neural tube (brain and spinal cord), from or to which the processes pass. The nervous system is often divided, therefore, into a *central* and a *peripheral* portion. The former, also known as the *cerebro-spinal axis*, includes the brain and spinal cord and contains the chief axial collections of nerve-cells; the peripheral portion, on the contrary,

contains the nerve-cells of the sensory ganglia and is principally composed of the nerve-fibres that pass to and from the end-organs. Intimately associated with and in fact a part of the peripheral nervous system, but at the same time possessing a certain degree of independence, stands the *sympathetic system*, which provides for the innervation of the involuntary muscle and glandular tissue throughout the body and the muscle of the heart.

When sectioned, the fresh brain and spinal cord do not present a uniform appearance, but are seen to be made up of a darker and a lighter substance. The former, the *gray matter*, owes its reddish brown color not only to the numerous nerve-cells that it contains, but also to its greater vascularity ; the hue of the lighter substance, the *white matter*, is due to its chief constituents, the medullated nerve-fibres, in conjunction with its relatively meagre blood supply.

THE NERVOUS TISSUES.

The Neurones.—The neurones, the essential morphological units of the nervous system, consist of the cell-body and the processes. The latter, as seen in the case of a typical motor neurone (Fig. 835), are of two kinds : (*a*) the branched protoplasmic extensions, the *dendrites*, which may be multiple and form elaborate arborescent ramifications that establish relations with other neurones, and (*b*) the single unbranched *axone* (neuraxis, neurite) that ordinarily is prolonged to form the axis-cylinder of a nerve-fibre, and, hence, is often termed the *axis-cylinder process.*

The **dendrites** are usually uneven in contour and relatively robust as they leave the cell-body, but rapidly become thinner, due to their repeated branching, until they are reduced to delicate threads that constitute the terminal arborizations, the *telodendria*, formed by the end-branches. The latter are beset with minute varicosities and finally end in terminal bead-like thickenings. The **axones**, slender and smooth and of uniform thickness, are much less conspicuous than the dendrites. They may be short and only extend to nearby cells ; or they may be of great length and connect distant parts that lie either wholly within the

FIG. 835.

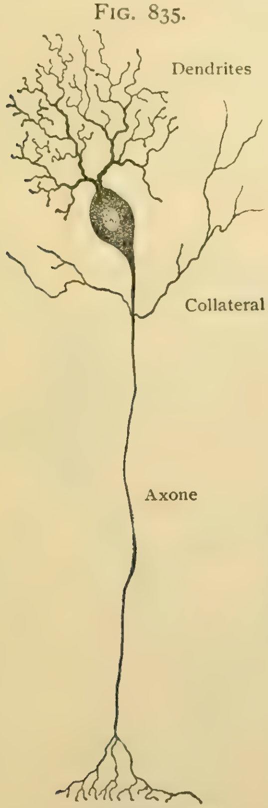


Diagram of typical neurone.

FIG. 836.

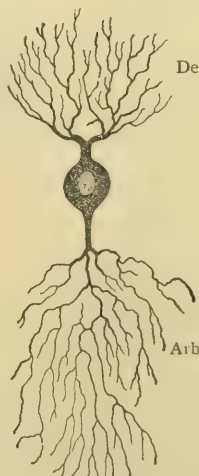


Diagram of nerve-cell of type II, in which axone is not prolonged as nerve-fibre.

cerebro-spinal axis (as from the brain-cortex to the lower part of the spinal cord) or extend beyond (as from the lower part of the cord to the plantar muscles of the foot).

On reaching their destination the axones terminate in end-arborizations (telodendria) of various forms, in a manner similar to the dendrites. According to the distribution of their axones, the neurones are divided into two classes. In those of the first, known as *cells of type I*, the axone is continued as a nerve-fibre and is, therefore, relatively long. Soon after leaving the cell-body such axones give off delicate lateral processes, the *collaterals*, which, after a longer or shorter course, break up into arborizations ending in relation with other and often remote neurones. Neurones of the second and much less frequent class, *cells of type II*, possess short axones that are not continued as nerve-fibres, but almost immediately break up into complex end-arborizations or *neuropodia* (Kölliker), limited to the gray matter.

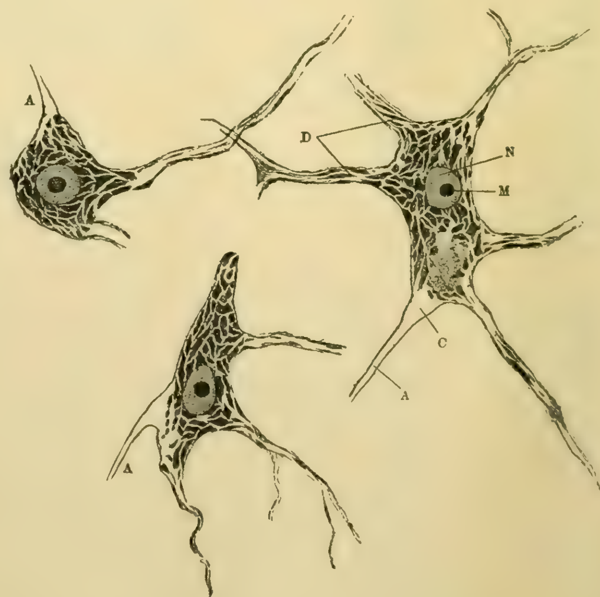
FIG. 837.

Semidiagrammatic representation of structure of neurone; *a*, axone.

The processes of the *sensory neurones*, as in the case of those constituting the spinal and other ganglia connected with afferent nerves, are so modified during development (Fig. 839) that later both dendrites and axones arise in common from the single robust stalk of an apparently unipolar cell. Branching T-like, one process (the dendrite) passes towards the periphery and the other (the axone) extends to and into the cerebro-spinal axis.

The **nerve-cells**, as the bodies of the neurones are called, possess certain structural details in common, although in some instances they present characteristics that suffice to identify them as belonging to particular localities. Nerve-cells are relatively large elements, those in the anterior horns of the spinal cord measuring from .070–.150 mm. in diameter, and contain a large spherical nucleus, poor in chromatin but usually provided with a conspicuous nucleolus. Their *cytoplasm* varies in appearance with the method of fixation and staining to such an extent that considerable uncertainty exists as to the relation of many described details to the actual structure of the cells. It may be accepted as established, however, that the cell-body of the neurone consists of a *ground substance*, homogeneous or finely granular, in which delicate *fibrillæ* and masses of *chromatophilic granules* are embedded; in addition, a variable amount of brown or blackish *pigment* is commonly present in the vicinity of the nucleus. The presence of the fibrillæ within the nerve-cell, long ago maintained by Max Schultze but later disregarded, has been placed beyond question by the researches of Apáthy, Bethe, Cajal and others. The significance and relations of the fibrillæ to the nerve-cell, however, have given rise to warm

FIG. 838.



Nerve-cells of human spinal cord stained to show Nissl bodies; *D*, dendrites; *A*, axones; *C*, implantation cone; *N*, nucleus; *M*, nucleolus. × 400.

discussion. The observations based upon the improved methods of silver-staining introduced by Cajal have contributed much towards the solution of these questions, and, at present, the most experienced histologists incline towards the view that the fibrillæ demonstrable within the nerve-cell are limited to the body and processes of that particular neurone and do not unite with the fibrillæ of other neurones. When adequately differentiated by successful staining, the fibrillæ form an intracellular net-work within the cell-body, from which they are continued into the dendrites and axone and in all cases end free in the terminal arborizations (Retzius).

After special staining with methylene blue, or other basic anilines, the chromatophilic granules appear deeply colored and arranged in groups or masses of varying form and size. Such aggregations, known as *Nissl bodies*, after the German histologist whose elaborate studies and theories concerning the structure of the nerve-cell have given prominence to these masses of "stainable substance," are usually most conspicuous in the vicinity of the nucleus. Collectively, they constitute the *tigroid substance* of Lenhossék and are least marked at the periphery of the nerve-cell. They are continued into the dendrites as elongated flakes or pointed rod-like tracts that finally are resolved into scattered granules along the processes. The axone, on the contrary, is not invaded by the Nissl bodies, and usually joins the nerve-cell at an area free from the stainable substance, the axis-cylinder process commonly arising from a slight elevation known as the *implantation cone*. Exceptionally, the axone may arise from one of the dendrites, either at its base or at a point some distance from the cell-body.

Notwithstanding the elaborate classification of nerve-cells and the theories based upon the Nissl bodies, their significance is still debatable, although in the light of the more recent studies by Carrier, Holmes and others it seems probable that they are normal constituents of the cell and are directly related to functional activity, undergoing increase under unusual stimulus.

Critical study of the structure of ganglionic nerve-cells has established the presence of four fundamental components within their cytoplasm. These are, according to Cowdry, (1) the Nissl bodies, (2) the mitrochondria, deeply staining minute rod-like granules, (3) an intracellular system of clefts or canaliculi, and (4) the neuro-fibrils. That these canaliculi are not artefacts is probable from their demonstration after staining *intra vitam* with a solution of pyronin, when the clefts appear as a network of clear, continuous, but tortuous spaces within the red-tinted cytoplasm.

Every neurone possesses at least one process, which is then an axone, although usually provided with both dendrites and axone. Very rarely more than a single axone is present. Depending upon the number of their processes, nerve-cells are described as *unipolar*, *bipolar*, or *multipolar*. The **unipolar condition** is often secondary, since two processes may be so blended for part of their course that they form a single process. Conspicuous examples of such relation are seen in the spherical nerve-cells composing the spinal and other ganglia connected with the sensory nerves. Primarily such neurones possess an axone and a dendrite that arise from opposite ends of what is for a time a spindle-shaped bipolar cell. During development, however, the unilateral growth of the cell-body towards the surface of the ganglion brings about the gradual approximation of the two processes until they fuse in the single extension into which the spherical or flask-like cell is prolonged. This process sooner or later undergoes a Y- or T-like division, one process, usually identified as the dendrite, passing to the periphery to end in the free terminal arborization, whilst the other, the axone, passes centrally to end in an arborization around the neurones lying within the cerebro-spinal axis.

FIG. 839.

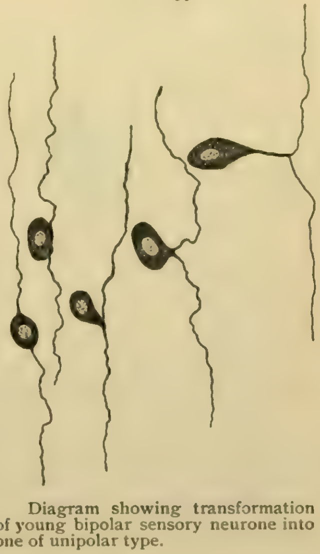


Diagram showing transformation of young bipolar sensory neurone into one of unipolar type.

Examples of **bipolar neurones**, in which the dendrite and axone pass from opposite sides of the spherical cell-body, are found in the retina and the ganglia

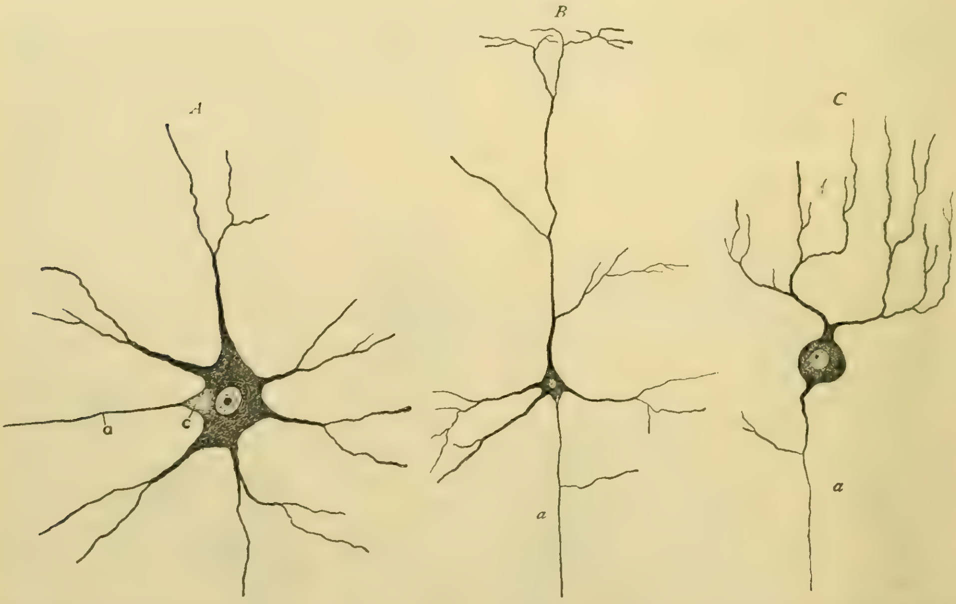
connected with the acoustic nerve. An interesting modification of bipolar neurones is presented by the olfactory cells, whose dendrites are represented by the extremely short processes embedded within the nasal mucous membrane, whilst the axones are prolonged as the fibres of the olfactory nerves into the cranial cavity to end in telodendria within the glomeruli of the olfactory bulb.

Fig. 840.

Bipolar neurones; *a*, from olfactory mucous membrane—dendrite is above; *b*, from retina. (*Modified from Cajal.*)

The cell-bodies of the **multipolar neurones,** which possess one axone and several dendrites, vary in form (Fig. 841). Some, as those within the sympathetic ganglia, are approximately spherical and of moderate size, with short delicate dendrites; many are of large size and irregularly stellate form, the dendrites passing out in all directions, as seen in the conspicuous motor neurones within the gray matter of the spinal cord; others possess a regular and characteristic form, as the flask-shaped cells of Purkinje within the cerebellum, or the pyramidal cells of the cerebral cortex. Certain multipolar neurones within the cerebral cortex, and especially those constituting the chief components of the granule layer of the cerebellum, are distinguished by the small size of their cell-bodies and the peculiar ramifications and claw-like telodendria of their dendrites (Fig. 945). Within the cerebellar cortex are likewise found examples of

Fig. 841.



Multipolar nerve-cells of various forms; *A*, from spinal cord; *B*, from cerebral cortex; *C*, from cerebellar cortex (Purkinje cell); *a*, axone; *c*, implantation cone.

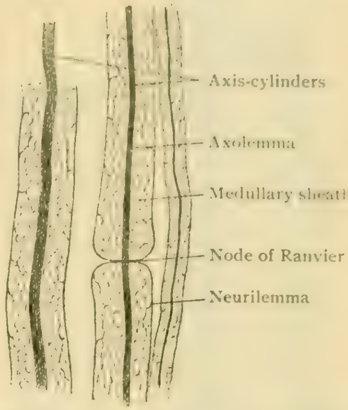
the multipolar neurones of Golgi's type II, whose axones almost immediately undergo elaborate branching within the gray matter to which they are confined.

The Nerve-Fibres.—From the foregoing considerations it is evident that the nerve-fibres are not independent elements, but that all are the processes of neurones—either the axones of those that are prolonged into fibres (type I), or the dendrites of those situated within the spinal and other sensory peripheral ganglia. Although neurones exist which are not continued as nerve-fibres, the latter are always connected

with neurones. Recognizing, therefore, that the nerve-fibres are only processes of neurones, their separate description is justified only as a matter of convenience.

The fundamental part of every nerve-fibre is the central cord, commonly known as the **axis-cylinder**, which is composed of threads of great delicacy, the *axis-fibrillæ*, prolonged from the nerve-cell and embedded within a semifluid interfibrillar substance, the *neuroplasm*, the entire cord perhaps being enclosed by a delicate structureless sheath, the *axolemma*. The existence of the axolemma as a distinct sheath, however, is questionable, the appearance of such investment not improbably being due to a local condensation of the framework of the medullary coat immediately around the axis-cylinder.

FIG. 842.



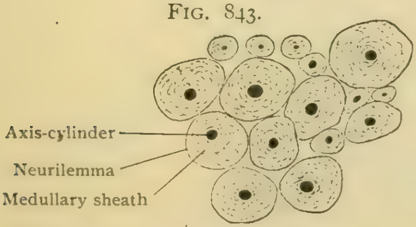
Medullated nerve-fibres, as seen in longitudinal sections of spinal nerve. × 500.

In the case of the typical fibres, such as form the chief constituents of the peripheral nerves distributed to various parts of the body, the axis-cylinder is surrounded by a relatively thick coat, known as the *medullary sheath*, outside of which lies a thin structureless envelope, the *neurilemma* or *sheath of Schwann*, that invests the entire nerve-fibre. In the case of fibres proceeding from neurones composing the sensory ganglia, the neurilemma is continuous with the nucleated sheath enclosing the individual ganglion-cells.

The **medullary sheath** consists of two parts, a delicate reticular *framework* and a fatty substance, the *myelin*, that fills the meshes of the supporting reticulum. The latter, arranged for the most part as anastomosing membranous lamellæ, that in transverse sections of the nerve-fibre appear as faint concentric lines, resists pancreatic digestion and fat-dissolving reagents, and was regarded by Ewald and Kühne as possessing properties similar to the keratin of horny substances and, hence, was named by them *neurokeratin*. The blackening after treatment with osmic acid and other reactions exhibited by myelin indicate its fatty nature, and it is probable that this substance exists during life in the form of a fine emulsion supported by the framework. When fresh, myelin appears highly refracting and homogeneous, and confers upon the medullated nerve-fibres their characteristic whitish color. It is, however, prone to post-mortem changes, so that after death it loses its former uniformity and presents irregular contractions and collections, or at the broken end of the fibre extrudes in irregular globules, due probably to fusion of the normal individual minute droplets into larger masses.

The medullary sheath is not uniformly continuous, but almost completely interrupted at regular, although in different fibres variable, intervals marked by annular constrictions. These constrictions, the *nodes of Ranvier*, correspond to narrow zones at which the medullary sheath is practically wanting and the neurilemma dips in and, somewhat thickened, lies in close relation with the axis-cylinder. According to Hardesty[1] the medullary sheath does not suffer complete suppression at the nodes, but is represented by part of its reduced framework which transverses the constriction, a conclusion which we can confirm. The nodes occur at regular intervals along the fibre, which they thus divide into a series of *internodal segments*. In general, the latter are longer in large fibres, where they have a length of about 1 mm., and shorter in those of small diameter, in which they may measure .1 mm. or less in length. The axis-cylinder passes uninterruptedly across the nodes, although it often presents a slight fusiform enlargement

FIG. 843.

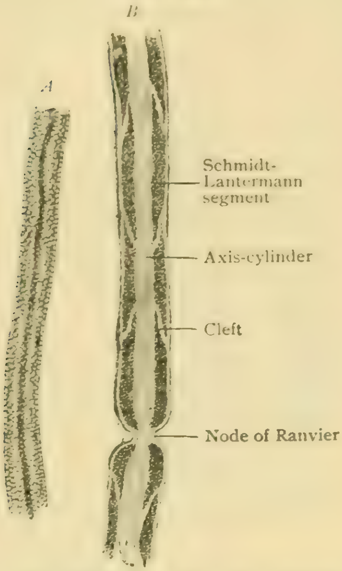


Medullated nerve-fibres in transverse section. × 550.

[1] Amer. Journal of Anatomy, vol. iv., 1905.

opposite each constriction (Ranvier). The neurilemma also suffers no break at the nodes, but is continuous from one segment to the other.

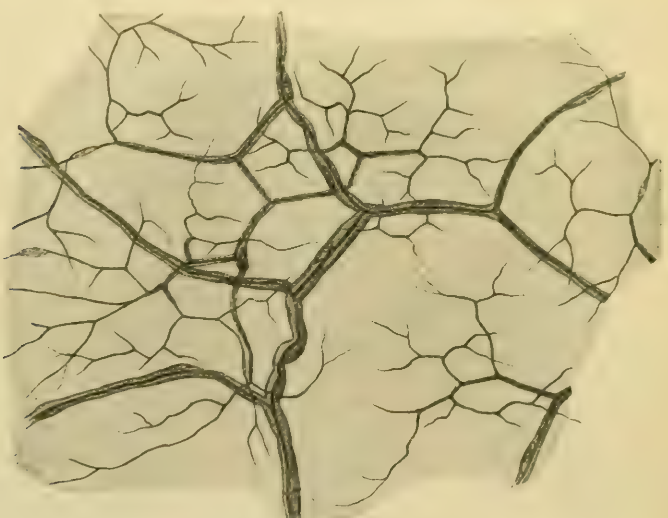
FIG. 844.



Medullated nerve-fibres after treatment with osmic acid; *A*, fibre showing reticulum within medullary coat; *B*, one showing same coat divided into segments. × 500.

In addition to the partial interruptions at the nodes, the medullary sheath after treatment with osmic acid frequently appears broken by clear narrow clefts that extend obliquely from the neurilemma to the axolemma and thus subdivide each internodal segment into a number of smaller tracts, known as the *Schmidt-Lantermann segments* (Fig. 844). The oblique clefts do not all extend in the same direction, even within the same internodal segment, since they are usually directed from without inward and towards the nodal constrictions and, therefore, have an opposed disposition at the ends of the same as well as of the adjoining segments. The significance of this subdivision is uncertain; many regarding the details as artefacts. According to Capparelli[1], however, the apparent clefts are in reality unstained membraneous septa that pass obliquely from the axolemma to the inner surface of the neurilemma and serve to hold the axis-cylinder in place and to enclose the myelin. The studies of Hatai[2] on the arrangement of the neurokeratin seem to support these conclusions. Within each internodal segment, beneath the sheath of Schwann, lies a single (sometimes more than one) small *neurilemma-cell* which consists of an elongated oval nucleus surrounded by a meagre amount of cytoplasm. These cells represent the remains of the formative elements (*sheath-cells*) that during the growth of the nerve-fibre were active in providing its envelope (page 1011).

FIG. 845.



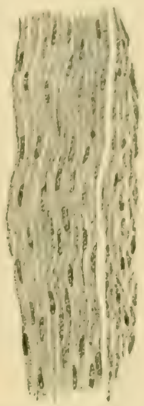
Medullated nerve-fibres becoming nonmedullated on approaching their termination. × 235.

Depending upon the presence or absence of the medullary sheath throughout the greater part of their course, nerve-fibres are distinguished as medullated or non-

[1] Archiv f. mikros. Anat. u. Entwick., Bd. 66, 1905.
[2] Journal of Comparative Neurology, vol. xiii., 1903.

medullated. The **medullated fibres** constitute the great majority of those making up the peripheral nerves and the tracts of the cerebro-spinal axis; the component fibres of the latter, however, while medullated are without the neurilemma. The **nonmedullated fibres**, on the other hand, are chiefly prolongations (axones) from the ganglion cells of the sympathetic system, although in the case of the olfactory nerves the fibres are also without a myelin-coat. The distinction between these two classes of fibres is relative rather than absolute, since every medullated nerve-fibre becomes nonmedullated before reaching its termination, central or peripheral.

FIG. 846.



Nonmedullated nerve-fibres in longitudinal section of splenic nerve. × 310.

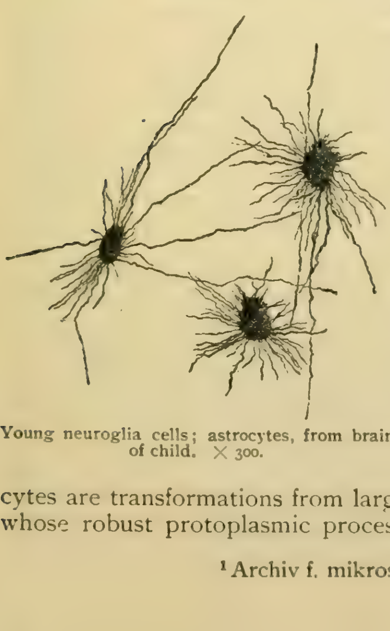
Medullated nerve-fibres vary greatly in thickness, the smallest having a diameter of only .001 mm., whilst the largest may measure as much as .020 mm. According to their diameter, as determined by Kolliker, the medullated fibres may be grouped as fine (.002–.004 mm.), medium (.005–.009 mm.), and coarse (.010–.020 mm.). In general, the thicker fibres are the longer and are the processes of large nerve-cells; conversely, the finer have shorter courses and belong to small cells. Although subject to many exceptions, the motor fibres are usually the thicker and the sensory the smaller.

Since there are many more nerve-fibres than nerve-cells, it is evident that the former must undergo division along their course. Such doubling always occurs at a point corresponding to a node of Ranvier, never within the internodal segment, the sheaths being continued over the two resulting fibres. On approaching their peripheral termination the branching becomes more frequent and the medullary sheath thinner until it ends, after which the axis-cylinder continues invested with only the attenuated neurilemma. The latter, now reduced to an extremely delicate covering beset with occasional nuclei, sooner or later disappears, the naked axis-cylinder alone being prolonged to end finally in the varicose threads of the telodendrion.

The **nonmedullated nerve-fibres proper**, also termed *pale fibres* or *fibres of Remak*, include those that are without the myelin sheath throughout their course. They are chiefly the axones of sympathetic neurones. Devoid of medullary sheath, these fibres, often .002 mm. or less in diameter, consist of only the axis-cylinder and the neurilemma, the latter being thinner and more delicate than on the medullated fibres. Like the latter, the pale fibres end in telodendria composed of naked axis-cylinders, bearing irregular varicosities.

Neuroglia.—The neurones (nerve-cells and fibres) within the cerebro-spinal axis are everywhere held together by a special supporting tissue known as neuroglia. The latter is primarily derived from the invaginated ectoblast lining the neural tube, certain elements, the *spongioblasts*, being devoted to the production of the neuroglia, while others, the *neuroblasts*, give rise to the neurones. At first the supporting tissue is represented by greatly elongated, radially disposed fibre-cells that often extend the entire thickness of the wall of the neural canal. Later, the neurogliar elements become differentiated into (*a*) those bordering the lumen of the canal, which are partly retained as the *ependymal cells*, and (*b*) those which have early migrated to more peripheral locations and given rise to stellate cells that are converted into spider-like elements, the *astrocytes*. Seen in chrome-silver preparations (Fig. 847) these appear as irregular triangular or quadrilateral cells from whose angles numerous delicate fibrillæ extend between the surrounding nervous elements. According to Rubaschkin,[1] the astrocytes are transformations from larger branched *gliogenetic cells*, by the conversion of whose robust protoplasmic processes the delicate *fibrillæ* that later form the chief

FIG. 847.



Young neuroglia cells; astrocytes, from brain of child. × 300.

[1] Archiv f. mikros. Anat. u. Entwick., Bd. 64, 1904.

constituents of the neuroglia arise. So long as neuroglia is being produced, as in the nervous axis of young animals, the large gliogenetic cells are present and directly concerned in the production of additional fibrillæ, their cytoplasm becoming progressively less granular and reduced through the various transition phases until in the final condition, as the small *glia cells*, little more than the nucleus remains. During these changes very many fibrillæ lose their connection with the cells and, in conjunction with the glia threads still attached to the astrocytes, form an elaborate interlacement in which the neuroglia cells, now reduced and for the most part devoid of processes, lie scattered at uncertain intervals.

In all parts of the central nervous system the **mature neuroglia** consists of essentially the same tissue, the differences presented in certain localities depending largely upon variations in its compactness. Everywhere the chief part of the supporting tissue consists of the intricate felt-work of fibrillæ, *glia-fibres*, as they are called, which are usually free but to some extent connected with the *spider-cells* or astrocytes. Where, however, the neuroglia borders the neural tube (the ventricles of the brain and the central canal of the spinal cord) as the *ependymal layer*, its arrangement exhibits peculiarities that call for later special mention.

In the immediate vicinity of the neurones the felt-work of the fibrillæ is unusually close, so that the cell-bodies and the roots of the processes are surrounded by a protecting sheath, the *glia-capsule*. This diminishes along the dendrites, and after these begin to branch the neuroglia no longer forms a complete special investment. The medullated nerve-fibres within the brain and spinal cord are also provided with delicate *neurogliar sheaths* which replace the neurilemma which on these fibres is wanting. These sheaths are prolonged for some distance on the fibres of the roots of the spinal nerves. The fibres of the optic nerve and of the olfactory tract are accompanied throughout their length by neurogliar sheaths, those of the remaining cranial nerves losing these envelopes shortly after leaving the brain (Rubaschkin).

FIG. 848.

Ependymal cells and adjacent neuroglia surrounding central canal of spinal cord of cat. × 75. (*Rubaschkin.*)

Beneath the pia mater the neuroglia is especially dense and forms the external *subpial layer* that everywhere invests the nervous mass, following all the inequalities of its surface. In this manner the pia mater is excluded and, except where its connective-tissue strands accompany the blood-vessels that enter the nervous mass, takes no part in the make-up of the supporting stroma. The subpial layer consists of a dense felt-work of glia-fibres, disposed in various planes, which are partly free and partly the processes of spider cells. Internally the layer fades into the adjoining diffuse neuroglia without demarcation. At the periphery the fibres often exhibit a radial disposition, their outer ends usually being somewhat expanded. Within the white matter the neuroglia, both in its distribution and density, is fairly uniform, although special tracts often separate the larger bundles of nerve-fibres. Its arrangement within the gray matter presents less uniformity, since more or less marked condensations occur where the nerve-cells are collected into nuclei, as conspicuously seen in the inferior olive.

Where the neuroglia borders the neural tube (especially the central canal of the spinal cord) it constitutes the **ependymal layer**, the peculiarities of which call for special mention. The immediate lining of the tube consists of a single layer of pyramidal epithelial elements, the *ependymal cells*, whose free surfaces or bases look towards the lumen, and the apices towards the surrounding nervous tissue. At least during the earlier years in man, and throughout life in many lower mammals, the free surface of each cell is beset with a number of hair-like processes that in their relations with the cytoplasm correspond to ordinary cilia. The pointed distal end of the ependymal cell is prolonged into a conical process that is directly continued into usually a single neurogliar fibre which, after a course of uncertain length becomes

lost in the surrounding complex of glia-fibres. In young tissue the apical processes often exhibit evidences of breaking up into a number of fine fibrillæ. Where the processes enter robust tracts of neuroglia, as in the posterior longitudinal septum of the spinal cord, they are of unusual length. In addition to the radially directed fibres connected with the ependymal cells, the fibre-complex of the ependymal zone includes many fibrillæ that are circularly and longitudinally disposed. Scattered glia cells, some stellate but mostly small, are also present and represent the elements from which the neuroglia-fibrillæ have been derived.

In the preceding account of the elements composing the nervous tissues the neurones have been regarded as the morphological units, each retaining its individual anatomical independence, although functionally closely related with other similar units. This conception, commonly referred to as the Neurone Doctrine and strikingly formulated by Waldeyer in 1891, stands in contrast to the prior views by which actual continuity was attributed to the nerve-cells by means of the union assumed to exist within the terminal net-works of their processes. The independence and true relation of the neurone was established largely through the convincing embryological investigations of His and the renewed study of the nerve-cells as demonstrated by the improved applications of the Golgi silver-impregnations, supplemented by the method of vital staining by methylene blue introduced by Ehrlich. The Neurone Doctrine has gained wide acceptance and the support of the most distinguished anatomists, among those who have materially strengthened its position being Kölliker, Ramón y Cajal, Retzius, Lenhossék, Waldeyer, van Gehuchten, and Edinger.

The neurone conception, securely founded as it is upon a vast mass of evidence collected from a wide field by the most painstaking and accurate observation, has not escaped challenge, and at present is assailed by a group of histologists headed by Apáthy and Bethe, who not only bitterly oppose the integrity of the neurone as an independent unit, but also strive to depose the nerve-cell from its dignity as the fundamental physiological factor. In 1897 Apáthy[1] published his observations on the structure of the ganglia of certain invertebrates, as revealed by a new mercuric gold-chloride method, and thereby established the important fact that the cell-body and processes of the neurone are pervaded by fine neurofibrillæ, thus confirming the fibrillar structure of the nerve-cell advanced by Max Schultze more than a quarter of a century before. Following Apáthy, Bethe[2] investigated the tissues of the higher animals and succeeded in demonstrating the existence of the neurofibrillæ within the neurones of man. According to these observers, the neurofibrillæ, although interlaced without junction within the cell-bodies, are independent threads, that are not confined to the neurones but pass beyond and unite with fibres from other sources. The neurofibrillæ, therefore, and not the nerve-cells, are the essential elements of the nervous system, the cells being only interposed along the path of conduction. Indeed, according to these views, the neurofibrillæ are independent of and, in a sense, foreign to the nerve-cells, leaving or entering the latter at pleasure and constituting by their union a continuous path of conduction from the receptive element to the muscle-fibre. Apáthy, moreover, assumes the existence throughout the central nervous system of a fibrillar net-work formed outside and between the nerve-cells by the neurofibrillæ from which the axones may arise independently of the nerve-cells. It is evident that if such be the case the conception of the neurone as an individual unit falls.

The criticism made by the newer school, that the supporters of the neurone theory relied upon methods which inadequately demonstrated the ultimate terminal relations (the assumed union in net-works) has been met by the introduction of the still newer methods of Beilschowsky and especially of Cajal, which have yielded preparations that demonstrate that the neurofibrillæ everywhere form net-works *within* the cell-bodies of the neurones, are confined to their processes, and even in their ultimate endings form ununited terminal arborizations. It seems, indeed, that, at present at least, the defenders of the neurone theory may with justice charge their opponents in turn with depending upon methods that only partially show the relations of the neurofibrillæ within the neurones. Retzius, than whom no more experienced and competent authority in this difficult field of research can be consulted, has recently reviewed the entire question and presented[3] most convincingly the facts that enable him, as well as the most distinguished anatomists of to-day, still vigorously to champion the Neurone Doctrine. After a critical and scientific discussion of the arguments advanced by Apáthy, Bethe and Nissl,[4] Retzius rests his case with little concern as to the verdict of those to whom facts and not speculation most appeal.

[1] Mitteilungen aus d. Zoolog. Station zu Neapel, Bd. xii., 1897.
[2] Allgemeine Anat. u. Physiol. des Nervensystems, 1903.
[3] Biologische Untersuchungen, N. F., Bd. xii., 1905.
[4] Die Neuronenlehre und ihre Anhänger, 1903.

The Nerve-Trunks.—The fibres composing the peripheral nervous system are grouped into the larger and smaller nerve-trunks which extend to various parts of the body. In the make-up of those that supply both muscles and sensory surfaces (integument or mucous membranes), as, for example, the median or the third division of the trigeminal nerve, three sets of fibres are included: (1) the efferent axones of motor neurones whose cell-bodies are situated within the spinal cord or brain; (2) the afferent dendrites of sensory neurones within the spinal and other sensory ganglia; and (3) the efferent axones of neurones within the sympathetic ganglia that accompany the spinal fibres to the periphery and serve for the innervation of the involuntary muscle of the blood-vessels and of the skin and the glands.

The nerve-fibres, the various kinds usually more or less intermingled, are grouped into bundles, the **funiculi**, which differ in number and diameter according to the size of the entire trunk that they form. Each funiculus is surrounded by a definite sheath of dense connective tissue, the *perineurium*, which is directly continuous with the delicate fibro-elastic tissue prolonged between the individual nerve-fibres as the *endoneurium*. When well represented, the sheath of the funiculus consists of concentric lamellæ of fibrous tissue which enclose *perineurial lymph-spaces*.

FIG. 849.

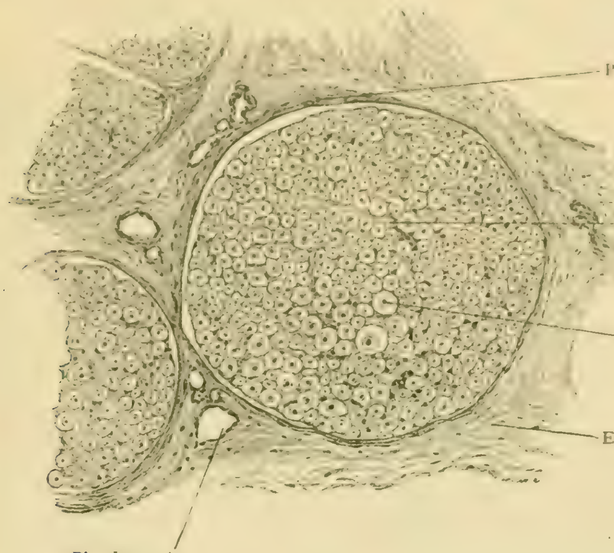
Transverse section of small nerve-trunk composed of loosely united funiculi. × 20.

The latter, lined by flattened connective-tissue plates, are in relation with the clefts between the nerve-fibres, on the one hand, and with the lymphatics within the interfunicular tissue on the other. Where, as usual, the nerve is composed of several funiculi, these are loosely bound together and the entire trunk so formed is invested by a general fibro-elastic envelope, the *epineurium*, in which course the blood-vessels and lymphatics. These envelopes of the nerve-trunk are continued over its branches, even onto its smallest subdivisions. The last representative of these coverings is seen on the individual fibres as the *sheath of Henle*, that surrounds the fibre and consists of flattened cells and delicate strands of connective tissue outside the neurilemma.

In cross-sections of the nerve-trunk (Fig. 850), the transversely cut individual medullated nerve-fibres appear as small circles, sharply defined by a fine outline (the neurilemma), each enclosing a deeply stained dot (the axis-cylinder in section). The interval between the latter and the neurilemma, corresponding to the space occupied by the myelin, usually appears clear and unstained with the exception of delicate and uncertain suggestions of membranous septa. In contrast with its unstained appearance in sections tinged with carmine, after the action of osmic acid or special hematoxylin staining (Weigert) the medullary substance exhibits a dark color and the axis-cylinder appears surrounded by a deeply tinted ring. The neuri-

lemma nuclei are occasionally seen as deeply stained crescentic figures that partially embrace the nerve-fibre, lying beneath the neurilemma within depressions in the medullary substance.

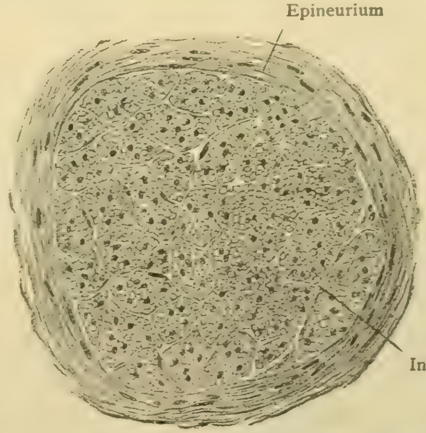
FIG. 850.



Transverse section of funiculus composed of nerve-fibres held together by endoneurium and surrounded by perineurium. × 175.

Viewed in cross-section, the nonmedullated fibres appear as small irregularly round figures arranged in groups that correspond to bundles (Fig. 851). When numerous, the latter are aggregated into secondary bundles between which extend delicate connective-tissue septa, continuous with the general envelope investing the nerve-trunk. The medullary substance being wanting, the pale fibres are of small size and often possess a diameter of less than .001 mm.

FIG. 851.



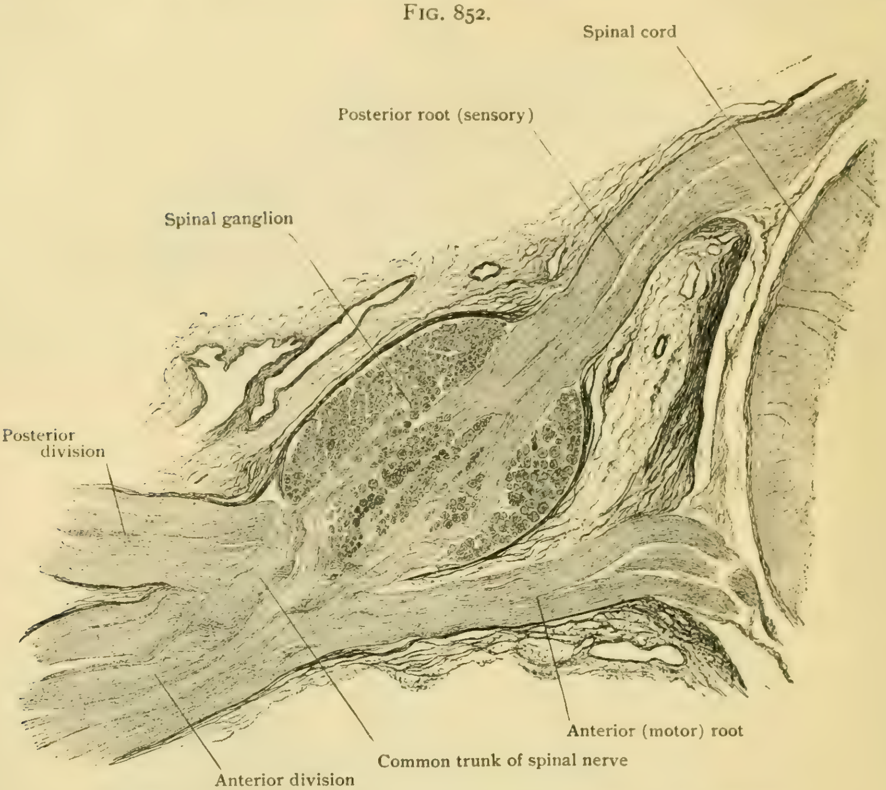
Transverse section of small splenic nerve consisting chiefly of nonmedullated fibres. × 200.

The Ganglia.—The cell-bodies of the neurones that constitute the sensory pathways within the peripheral nerves and of the neurones of the sympathetic system are collected at various points into aggregations known as ganglia. Familiar examples of the latter are the spinal ganglia on the posterior roots of the spinal nerves, certain cranial ganglia (as the Gasserian connected with the fifth nerve, the acoustic with the eighth, and those on the trunks of the seventh, ninth and tenth cranial nerves), and the sympathetic ganglia along the gangliated cords and within various plexuses of the sympathetic.

A longitudinal section of a **spinal ganglion** (Fig. 852), which may be taken as a type of such collections, shows the entire ovoid mass to be enclosed by a *fibrous capsule* continuous with that ensheathing the nerves. Immediately beneath the capsule the ganglion-cells are arranged in a fairly continuous layer of varying thickness, while the cells, more deeply placed, are broken up into groups by the tracts of

intervening nerve-fibres, a small amount of connective tissue prolonged from the endoneurium of the nerve-bundles and accompanying the blood-vessels being also

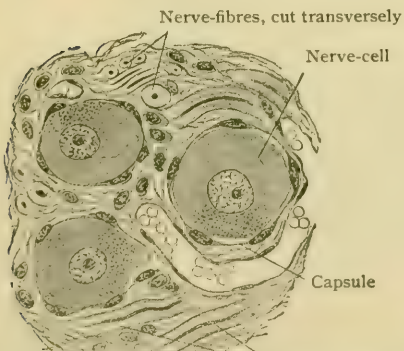
FIG. 852.



Section of spinal nerve, showing its roots, ganglion, common trunk and primary divisions. × 10.

present. The chief ganglion-cells are from .060–.080 mm. in diameter, but some measure as much as .170 mm. and others as little as .025 mm. In sections (Fig. 853) they usually appear round or oval, since only exceptionally are their processes to be seen. Each cell is enclosed by a richly nucleated *capsule* which is continuous with the sheath of the nerve-fibres. Most of the many other oval nuclei that are conspicuous in sections of the ganglia belong to the neurilemma of the nerve-fibres and, hence, are seen as chains extending in different planes. Although many of the nerve-cells within the spinal ganglia are the cell bodies of the sensory neurones, whose processes course as medullated fibres within the spinal nerves, many more are small cells, whose axones never acquire a medullary coat and, dividing into peripheral and central branches, run within the trunks and posterior roots of the nerves as nonmedullated fibres. Based largely on the behavior of their axones, Dogiel[1] has described eleven types of cells within the ganglia. Ranson regards the "large" and "small" cells, whose axones become medullated and nonmedullated fibres respectively, as an important grouping,

FIG. 853.



Section of spinal ganglion, showing nerve-cells surrounded by nucleated capsules. × 300.

[1] Der Bau der Spinalganglien, Jena, 1908. Dogiel describes eleven varieties of nerve-cells.

and has traced the nonmedullated fibres along the dorsal roots into the spinal cord. The presence of fibres probably derived from sympathetic neurones has been demonstrated.

The *sympathetic ganglia* are represented by those of the great gangliated cords, certain cranial ganglia (ciliary, spheno-palatine, otic, and submaxillary), the ganglia within the three prevertebral plexuses, and the innumerable small and often microscopic ganglia associated with the muscular tissue of the digestive, respiratory and uro-genital tracts, in the heart and in the various glands.

In their general structure the sympathetic ganglia are similar to those connected with the spinal nerves, forming definite masses enclosed by a fibrous capsule, from which connective-tissue processes pass into the interior of the ganglion for the support and separation of the nervous elements. The individual ganglion-cells—unipolar, bipolar or multipolar—are ensheathed by nucleated capsules continuous with the neurilemma of the nerve-fibres. The sympathetic ganglion-cells are variously related to the terminal ramifications of (*a*) other sympathetic neurones and of (*b*) the neurones of the central nervous system (by way of the white rami fibres or their equivalents). In both cases, the ramification of the nonmedullated and fine fibre in the one and of the medullated fibre in the other, a pericellular plexus, commonly encloses the cell-body. In the lower vertebrates (amphibians and reptiles), the spinal fibre frequently winds spirally around the single process of the ganglion-cell before breaking up into the pericellular plexus (Huber[1]). The broader relations of the component nervous elements of the spinal ganglia are considered in connection with the Sympathetic System (page 1354).

FIG. 854.

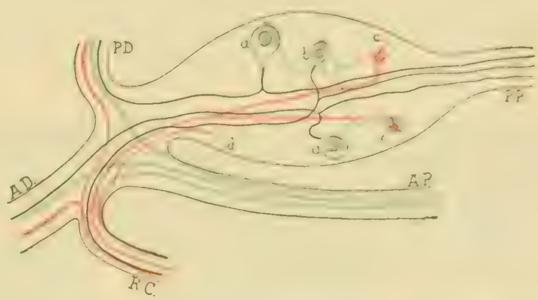
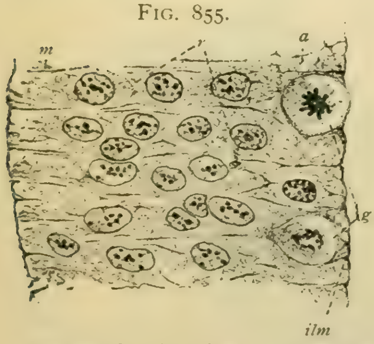


Diagram of constituents of spinal ganglion; blue lines represent efferent fibres; black, afferent; red, sympathetic; *a*, sensory ganglion cells; *c*, cells of type II, whose axones end (*b*) around sensory cells; *d*, sympathetic neurone; *AR*, *PR*, anterior and posterior roots; *AD*, *PD*, anterior and posterior primary divisions of spinal nerve; *RC*, ramus communicans.

DEVELOPMENT OF THE NERVOUS TISSUES.

Reference to the account of the early development of the nervous system (page 26) will recall the fact that the neural groove, later the neural tube, is lined by invaginated and thickened ectoblast from which the essential nervous tissues are derived. For the fundamental facts concerning the histogenesis of these tissues we are in large measure indebted to the labors of His, whose account, supplemented by the important contributions of Kölliker, Cajal, Lenhossék, Schaper and others, forms the basis of our knowledge concerning these processes. Although in its principal features the histogenesis is similar in all parts of the neural tube, in that portion which becomes the spinal cord the changes are most typical and will, therefore, be here described.

FIG. 855.



Segment from lateral wall of neural tube of pig embryo of 5 mm.; syncytium replacing distinctly outlined cells. *a*, inner zone; *g*, germinal cells; *ilm*, internal limiting membrane; *m*, peripheral zone; *r*, radial strands of cytoplasm. × 690. (*Hardesty*.)

During the approximation and closure of the neural tube the cells composing its wall undergo active proliferation, whereby the wall, at first composed of only one or two rows of definitely outlined cells, is converted into a multinucleated tract in which the cell boundaries disappear and the nuclei lie embedded within a general protoplasmic sheet or *syncytium* (Hardesty[2]). The large dividing elements within the latter, the *germinal cells* of His, are conspicuous on account of their mitotic figures and are situated close to the lumen of the neural tube. His regarded them as special cells directly concerned in the production of the neurones, a conclusion, however, that has not

[1] Journal of Morphology, 1899.
[2] Amer. Journal of Anatomy, vol. iii., 1904.

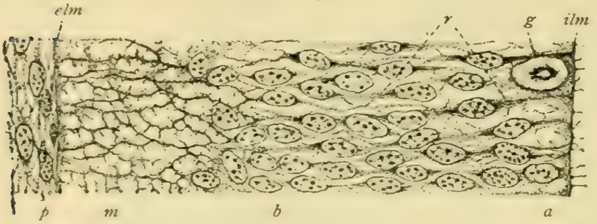
been sustained (Kölliker, Schaper and others) since the primary germinal cells probably only represent proliferating elements engaged in forming what for a time is an undifferentiated tissue.

The cells composing the neural wall are at first in close contact, their blended cytoplasm (syncytium) forming an almost unbroken sheet. Soon, however, this continuity is interrupted in consequence of the longitudinal expansion of the tissue and the appearance of spaces, and the cell-substance is resolved into a delicate reticulum, the *myelospongium* of His, which becomes condensed at the inner and outer margins of the wall of the neural tube into the *internal* and *external limiting membrane*.

The meshes of the reticulum enlarge, the intervening nucleated tracts of cytoplasm elongate and the increasing nuclei become radially disposed. By reason of these changes the elements next the lumen of the tube assume a columnar form and radial arrangement and become the *primary ependymal cells*. The remaining elements, appropriately named the *indifferent cells* (Schaper), increase in number in consequence of the continued division of the germinal cells and gradually become collected as the *nuclear layer* at some distance beyond the ependymal zone.

Meanwhile and very early, the peripheral portion of the supporting framework adjoining the outer border of the neural wall becomes denser and free from nuclei and is converted into the *marginal zone* (Randschleier of His), that is continuous with the delicate reticulum pervading the other parts of the wall. The indifferent cells later differentiate into (*a*) the *spongioblasts* from which the characteristic constituents of the definite supporting tissue, the neuroglia, are derived, and (*b*) the *neuroblasts* that are directly converted into the neurones. Within the resulting cell-complex that for a time occupies the greater part of the wall of the neural tube, it is difficult to distinguish with certainty between the neuroglia and neuron-producing elements, since both are often elongated in shape and prolonged into processes.

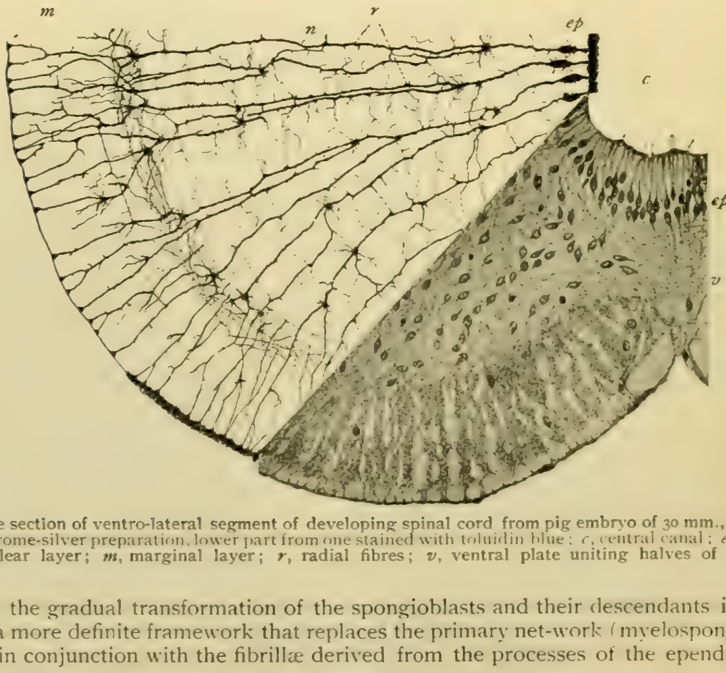
FIG. 856.



Segment of wall of neural tube of pig embryo of 10 mm.; radial strands (*r*) of syncytium and differentiation of ependymal (*a*), nuclear (*b*) and marginal (*m*) layers; *ilm*, *elm*, internal and external limiting membrane; *g*, dividing cell; *p*, pia mater. × 690. (*Hardesty*.)

Histogenesis of the Neuroglia.—In addition to the extension, condensation and moulding (by the developing nerve-cells and fibres) that the primary syncytial meshwork undergoes

FIG. 857.



Transverse section of ventro-lateral segment of developing spinal cord from pig embryo of 30 mm., upper part of figure from chrome-silver preparation, lower part from one stained with toluidin blue; *c*, central canal; *ep*, ependymal layer; *n*, nuclear layer; *m*, marginal layer; *r*, radial fibres; *v*, ventral plate uniting halves of cord. × 240. (*Hardesty*.)

(Hardesty), the gradual transformation of the spongioblasts and their descendants into fibrillæ establishes a more definite framework that replaces the primary net-work (myelospongium), and eventually, in conjunction with the fibrillæ derived from the processes of the ependymal cells,

gives rise to the definite supporting tissue, the neuroglia. According to Hardesty, the glia-fibres arise within the syncytial tissue independently of the neuroglia cells, a view in direct opposition to the observations of Rubaschkin, who attributes to the descendants of the spongioblasts, the gliagenetic cells, a positive rôle in the production of the fibres. Accepting the conclusions of the last-named investigator, the successive stages of the cells concerned in the production of the general neurogliar tissue are represented by the *spongioblasts*, the *gliogenetic cells*, the *astrocytes*, and, finally, the *glia cells*. The primary *ependymal elements* are succeeded by the epithelium which lines the ventricles and the central canal of the spinal cord. Their peripherally directed processes are in large part transformed into glia-fibres and thus, along with the processes of the spider cells, contribute to the formation of the neurogliar felt-work. The accompanying illustration (Fig. 857), taken from Hardesty's paper, affords an instructive comparison of the appearance of the young supporting tissue after true staining with approved reagents (Benda) and after silver precipitation methods (Golgi) upon which so much reliance has been placed. The silver picture shows the classic long neurogliar fibres extending the entire thickness, but fails to reveal the wealth of supporting tissue and nuclei. To what extent the mesoblastic ingrowths that follow the penetrating young blood-vessels into the neural wall take part in the production of the distinctive neurogliar framework is admittedly difficult to determine (Hardesty); that such tissue, however, contributes to the support of the nervous elements is certain.

Histogenesis of the Neurones.—The neuroblasts are distinguishable with certainty from the spongioblasts as soon as they are provided with nerve-processes. The latter appear as outgrowths from the pointed and peripherally directed ends of the developing nerve-cells, invade the marginal zone, and later emerge from the wall of the immature cord as the ventral or anterior root-fibres of the spinal nerves (Fig. 858). The deeper tint of their distal ends after staining, their tendency to collect in converging groups, and the uniform width of the outgrowing nerve-processes are distinctive characteristics of the neuroblasts (His[1]). The first, and for a considerable time the only processes with which the neurones are provided correspond to the axones that become the axis-cylinders of the efferent (motor) nerves. Subsequently other processes, the dendrites, grow out in various directions from the cell-bodies of the young neurones.

FIG. 858.

Portion of spinal cord of human embryo, showing development of ventral root-axones as outgrowths from ventral neuroblasts. × 300. (*After His.*)

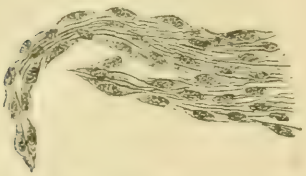
Development of the Peripheral Nerves.—According to the teaching of His, accepted by most anatomists, the axis-cylinder of the entire future nerve-fibre is formed by the peripheral growth of the original nerve-process of the neuroblast. The assumed development of the nerve-fibre by the union of a number of segments (Balfour, Dohrn, and others, and, more recently, Bethe and O. Schultze) is not in accord with renewed investigations, and the findings upon which the composite theory of the fibre is based are open to different interpretation (Kölliker, Retzius).

According to Bardeen,[2] the development of the peripheral spinal nerves is briefly as follows: The motor neuroblasts and the sensory spinal ganglion-cells send out processes of considerable thickness, all of which soon begin to give rise at their extremities to groups of *fibrillæ*, which increase in thickness and length and, in turn, at their extremities give rise to new groups of fibrils. At first these proceed as naked bundles, but soon become surrounded with nucleated fusiform ***sheath-cells*** which thus enclose the early embryonic nerve, and may contain hundreds of fibrillæ. After a nerve has become distended by ingrowth of new fibrils from behind, the proliferating sheath cells begin to wander from the periphery in among the fibrillæ and give rise by anastomosis of their processes to a net-work that divides the original fasciculus into a number of secondary bundles. The intrafascicular cells increase rapidly, the process of subdivision

[1] Die Entwickelung des menschlichen Gehirns, 1904.
[2] Amer. Journal of Anatomy, vol. ii., 1903.

continues and the bundles of fibrillæ become progressively smaller and more compact until, surrounded by membranous septa, they correspond to the *axis-cylinders* of the individual nerve-fibres, enclosed by the *neurilemma* and its cells. The *endoneurium* appears comparatively late and, like the neurilemma, is a product of the mesoblast. Later, condensations of the mesoblast around the definite bundles of nerve-fibres and about the entire nerve-trunk provide the *perineurium* and the *epineurium* respectively. During its course to the periphery the young nerve gives rise to numerous branches, the points of outgrowth being indicated by a preparatory increase of the peripheral cells which often form a tubular projection into which the nerve-fibrillæ grow. The *proximal plexuses* (such as the brachial or lumbar) are formed during the outgrowth of the nerves from the region of the central nervous system; the coarser *distal plexuses* arise during the extension of the branches to the various parts for which they are destined; whilst the finer *terminal plexuses* are established during the development of functional unity between the nerve-fibres and the structures to which they are distributed.

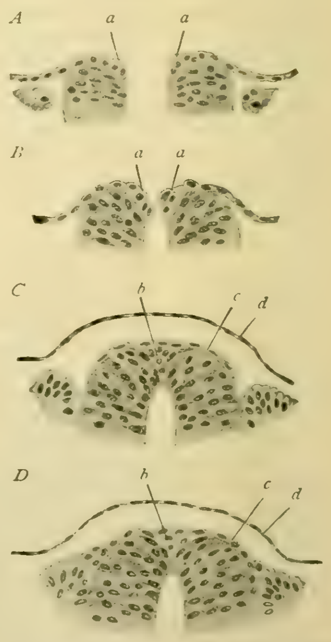
FIG. 859.



Developing intercostal nerve of pig embryo of 10 mm.; tip of nerve is composed of fibrils surrounded by sheath-cells. × 360. (*Bardeen.*)

The *medullary sheath* is a comparatively late acquisition, since it does not appear until about the fourth month of fœtal life. Within the central nervous system the tracts of nerve-fibres obtain their medullary coat at different times (some not until after birth), a variation that is of much service in enabling the anatomist to trace the course of the individual paths of conduction. The origin and method of formation of the medullary substance has been, and in fact still is, a subject of discussion. It is, however, certain that its production is not dependent upon the neurilemma, since the medullated fibres within the cerebro-spinal axis are devoid of this sheath, and, further, that the myelin sometimes appears before the neurilemma (Kolster, Bardeen). While it is doubtful whether the myelin is directly formed from the outer part of the axis-cylinder, as suggested by Kölliker, it is probable that this structure exerts some influence resulting in the deposit of the myelin-droplets either from the blood (Wlassak), or from the apparently fluid substance that after a time surrounds the axis-cylinder (Bardeen). Regarding the formation of the *framework* supporting the droplets of myelin, Hardesty[1] inclines to the view that certain sheath cells, which appear during medullation, are probably concerned. From the foregoing account it is evident that the axis-cylinder is derived from the ectoblast and the neurilemma from the ectoblast; the origin of the medullary sheath is still undetermined, but most probably is also ectoblastic.

FIG. 860.



Transverse sections of dorsal region of human embryos, showing early differentiation of spinal ganglion; *A*, *B*, neural tube still open; *C*, *D*, tube closed; *a*, ganglion-ridges; *b*, fused ridges; *c*, outgrowth to form ganglion; *d*, ectoblast. × 230. (*Lenhossék.*)

Development of the Ganglia.—The origin of the afferent (sensory) neurones, whose cell-bodies are situated within the spinal and other ganglia, is entirely different from that of the efferent (motor) ones above described. In the case of the spinal nerves, the development of the ganglia proceeds from a group of ectoblastic cells that form a ridge, the *ganglion-crest*, on the margin of either lip of the still open neural tube (Fig. 860), just where the general ectoblast passes into that lining the groove. On approximation of the lips of the latter, the cells of the ganglion-crests fuse into a wedge-shaped mass that completes the closure of the neural tube and constitutes a centre of proliferation from which the cells migrate outward over the dorso-lateral wall of the tube. The proliferation is not uniform but most marked at points that correspond to the mesoblastic somites, in consequence of which a series of segmentally arranged cell-aggregations appears on each side of the neural tube. These collections are the anlages of the spinal ganglia. Within them certain cells soon become fusiform and, assuming the rôle of neuroblasts, send out a process from either end. One process—the axone—grows centrally, while the other—the dendrite—extends peripherally and becomes the chief part of a sensory nerve-fibre. The subsequent growth of the neurone is not symmetrical, but to one side, and so

[1] Amer. Journal of Anatomy, vol. iv., 1905.

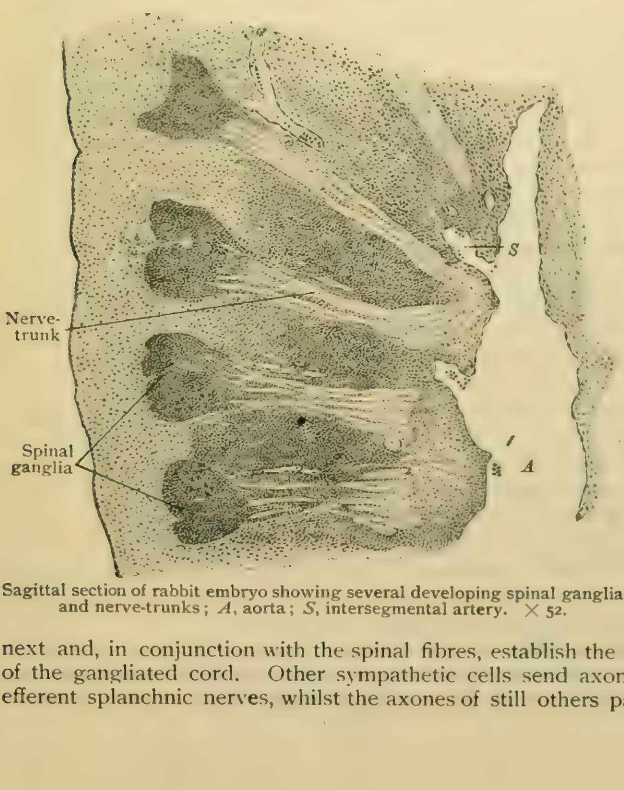
ordered that the two processes are approximated and finally joined to the cell-body by a common stalk (Fig. 839), the neurone being thus converted into an unipolar ganglion-cell. The centrally directed processes, the later posterior root-fibres of a spinal nerve, grow into the developing cord and enter the peripheral zone (later the white matter) to end, when their development is completed, at various levels in relation with neurones formed within the neural axis. The peripherally directed processes of the spinal sensory neurones, on the other hand, mingle with the axones from the motor neurones to form the mixed nerves distributed to the various parts of the body. The essential parts of the sensory neurones, the cell-body and the processes, are derived from ectoblastic elements, as well as the sheaths of the fibres, while the sheath of the entire ganglion is contributed by the mesoblast.

FIG. 861.

Cross-section of part of dorsal region of human embryo, showing developing spinal ganglion; *dz*, *vz*, *mz*, dorsal, ventral and marginal zones of spinal cord; *dr*, *vr*, dorsal and ventral root-fibres of spinal nerve (*n*); *sg*, spinal ganglion on dorsal root. × 85.

The development of the **sympathetic ganglia**, which include essentially three sets—those of the gangliated cords, those of the prevertebral plexuses (cardiac, solar and hypogastric), and the terminal —has given rise to much discussion. According to one view, the sympathetic neurones have an independent origin and only secondarily form connections with the cerebro-spinal nerves. The other view, on the contrary, regards the sympathetic neurones as the direct descendents of neurogenetic elements derived from the developing spinal nerves. The evidence in support of the last view is so convincing that there is little question as to the correctness of its principle, although many details of the process, as relating to man, are still to be studied. It is, however, equally true that the sympathetic ganglia are neither produced by constriction and isolation of parts of the spinal ganglia, as sometimes assumed, nor by the migration of fully differentiated ganglion-cells, but, as emphasized by Neumayer, from undifferentiated neuroblasts which undergo *in loco* their development. The earliest suggestions of definite sympathetic ganglia in the human embryo appear about the beginning of the second fœtal month as aggregations of cells at the distal ends of the visceral rami of the developing spinal nerves. From these cells are derived the definite sympathetic neurones of the gangliated cord, as well as those which follow the mesial ingrowth of the spinal fibres for the production of the prevertebral and terminal ganglia. The lateral ganglia thus formed constitute for a time a series of isolated nodes; subsequently these are connected by the differentiation of sympathetic axones which grow from one ganglion to the next and, in conjunction with the spinal fibres, establish the longitudinal commissural strands of the gangliated cord. Other sympathetic cells send axones centrally and give rise to the efferent splanchnic nerves, whilst the axones of still others pass to the growing spinal nerves.

FIG. 862.

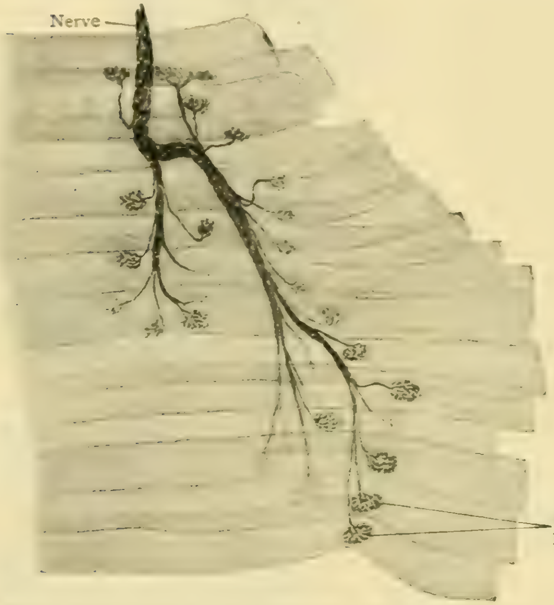


Sagittal section of rabbit embryo showing several developing spinal ganglia and nerve-trunks; *A*, aorta; *S*, intersegmental artery. × 52.

NERVE-TERMINATIONS.

The terminations of the fibres composing the peripheral nerves—the axones of certain motor neurones situated within the cerebro-spinal axis and the sympathetic system and the dendrites of the neurones of the sensory ganglia—supply the means by which the various structures of the body are brought into intimate relation with the nervous system. Some of these terminations transfer impulses resulting in muscular contractions; others convey impressions that produce various sensations (pain, pressure, muscle-sense, temperature). The nerve-terminations, therefore, may be grouped according to function into *motor* and *sensory endings*.

FIG. 863.



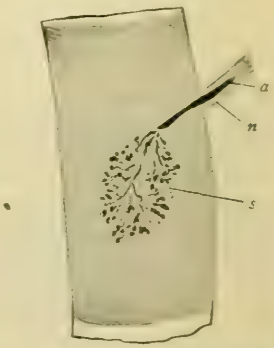
Motor nerve-endings in voluntary muscle; bundle of nerve-fibres is seen separating to supply the individual muscle-fibres. × 160.

MOTOR NERVE-ENDINGS.

The motor endings include (*a*) terminations of the axones of neurones situated within the motor nuclei of the spinal cord and brain-stem that pass to voluntary muscle; (*b*) terminations of sympathetic neurones that end in involuntary muscle and (*c*) in cardiac muscle.

Endings in Voluntary Muscle.—On approaching their peripheral destination the medullated nerve-fibres branch repeatedly, each fibre in this manner coming into relation with a number of muscle-fibres. When the medullated nerve-fibre reaches the muscle-fibre which it supplies, its medullary sheath abruptly ends and the neurilemma becomes inseparably fused with the sarcolemma, whilst the axis-cylinder passes beneath this sheath to terminate in an *end-plate*. The latter appears as an oval area, from .040–.060 mm. in its greatest diameter, which is applied to the muscle-substance; in profile it shows a slight projection beyond the contour of the muscle-fibre, although this is often wanting. Embedded within a general nucleated sheet of granular protoplasm, the *sole-plate*, lie the brush-like terminal arborizations of the axis-cylinder formed of irregular varicosites and club-shaped ends. From the details of the development of the motor end plates, as described by Bardeen, it is probable that the granular sole-plate and its nuclei are differentiated from the sarcoplasm and the nuclei of the muscle-fibre respectively. The much discussed relation of the end-plate to the sarcolemma—whether outside or beneath—seems to be decided in favor of a subsarcolemmal position, since the muscle-sheath appears subsequently to the formation of the motor-ending, a fact that explains the apparent piercing of the sarcolemma by the axis-cylinder. Usually each muscle-fibre is provided with a single motor end-plate, which may lie at an equal or unequal distance from the ends of the fibre. Exceptionally two end-plates may be found on one muscle-fibre, in which case the endings lie near each other.

FIG. 864.



Motor nerve-ending in voluntary muscle; *a*, axone terminating in end-plate; *n*, neurilemma; *s*, sole-plate. × 400.

Endings in Involuntary Muscle.—The terminations of the axones of the sympathetic neurones supplying the nonstriated muscle are comparatively simple. The neurones contributing the immediate fibres of distribution usually occupy the nodal points of plexuses from which bundles of nonmedullated nerve-fibres extend to and enclose the muscle fasciculi. Entering the latter the nerve-fibres divide into delicate varicose threads that pass between the muscle-cells, parallel with their long axes. As they course within the intercellular substance, the varicose fibrils give off short lateral branches that end, as does also the parent fibre, in minute terminal knots on the surface of the muscle-cells, often in the vicinity of the nucleus. Probably by no means every muscle-cell individually receives a nerve-ending, a longitudinal group including three or four rows of muscle-cells lying between two adjoining terminal nerve-fibrils (Huber).

FIG. 865.

Nerve-ending in involuntary muscle. (*Huber.*)

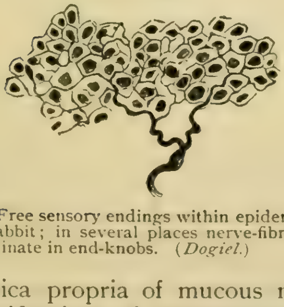
Endings in Cardiac Muscle.—These, also the terminations of sympathetic neurones, have been studied by, among others, Cajal, Retzius, Huber and Smirnow. According to the last-named investigator, the varicose nerve-fibrils may be followed between the muscle-cells, during which course side branches arise that, as well as the main fibril, terminate on the muscle elements in endings of varying complexity. In some cases these are merely minute simple end-knots, resembling those found in involuntary muscle ; in other cases they are more elaborate and consist of a group of secondary fibrillæ bearing nodular endings, the whole recalling somewhat the motor end-plates in striped muscle. It is probable that most of the cardiac muscle-cells are in direct relation with nerve-endings (Huber).

SENSORY NERVE-ENDINGS.

Since the sensory endings are the peripheral terminal arborizations of the neurones whose cell-bodies lie in the spinal and other sensory ganglia, such telodendria are functionally the *beginnings* of the paths conducting the sensory stimuli to the central nervous system. According to their relations to the surrounding tissue, the sensory endings are broadly grouped into *free* and *encapsulated.*

Free Sensory Endings.—These endings include vast numbers of nerve-terminations found in the skin and the mucous membranes, chiefly within the epithelium but to some extent also within the connective tissue strata. As a rule the sensory (afferent) nerve-fibres do not branch to any extent until near their peripheral destination, where they undergo repeated divisions, always at a node of Ranvier and in various directions. The medullary sheath of the main fibre is retained until close to its termination, although some of its branches may course as nonmedullated fibres for a considerable distance before ending or entering the epithelium. In the skin—and the same general plan applies to the mucous membranes—the fibres destined for the epidermis lose their myelin coat beneath the basement membrane and enter the epithelium as vertically coursing nonmedullated fibrils. Within the epidermis they break up into numerous delicate fibrils which undergo further division into still finer varicose threads that ramify between the cells of the stratum germinativum and terminate in minute free **end-knobs** (Fig. 866). Although an intracellular position of these nerve-endings has been described by various writers, it is probable that the endings are extracellular and lie upon the surface of and not within the epithelial elements. Similar, but far less numerous, free endings, varicose and club-like in form, occur within the connective tissue layers of the skin and the tunica propria of mucous membranes. Within the integument, conspicuous end-ramifications of sensory neurones surround the hair follicles, lying upon the outer surface of the glassy membrane.

FIG. 866.



Free sensory endings within epidermis of rabbit; in several places nerve-fibrillæ terminate in end-knobs. (*Dogiel.*)

The **tactile cells of Merkel**, found in the deeper layers of the epidermis, represent a somewhat more differentiated form of intraepithelial terminations and suggest transitions to the more specialized end-organs. In these endings the nerve-fibrils terminate in cup-shaped expansions or menisci, against which rest the modified epithelial cells. The latter may be regarded as an imperfectly differentiated *neuroepithelium*, examples of which are seen in the gustatory cells in the taste buds and in the highly specialized visual and auditory cells in the retina and in the organ of Corti respectively.

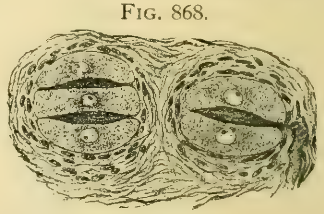
FIG. 867.

Tactile cells of Merkel lying within interpapillary epithelium; broken line (*e*) indicates junction of epithelium and connective tissue layer; (*n*) nerve passing into epithelium. × 160. (*Worthmann.*)

Encapsulated Sensory Endings.—In their most highly developed forms these endings (**corpuscula nervorum terminalia**) are represented by relatively large special end-organs in which the terminations of the axis-cylinder are enclosed within an elaborate laminated capsule. The latter, however, is more often present as a much simpler and thinner envelope consisting of strands of fibrous tissue.

Transition forms between the intraepithelial tactile cells above noted and the more specialized encapsulated end-organs, always within the connective tissue, are seen in the *corpuscles of Grandry* (not found in man but conspicuous in the skin covering the bill and in the tongue of many water-fowl), in which the nerve ends in a disc-like expansion enclosed between large modified epithelial cells and the neuromuscular and neurotendinous end-organs, presently to be described (page 1020).

FIG. 868.



Two corpuscles of Grandry from bill of duck; nerve is seen entering corpuscle on right. × 265.

The group of simpler encapsulated endings includes three well-known examples: the *end-bulbs* and the *genital corpuscles of Krause* and the *corpuscles of Meissner*, all of which possess a common structural plan—interwoven telodendria embedded within a semifluid interfibrillar substance and surrounded by a thin fibrous envelope.

FIG. 869.

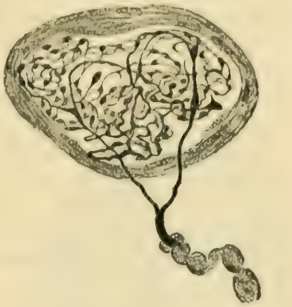
Two end-bulbs of Krause from human conjunctiva. (*Dogiel.*)

The End-Bulbs of Krause.—These endings include a variety of irregularly spherical or ellipsoidal bodies found in the edge of the eyelid, the conjunctiva and corneal margin, the lips and the oral mucous membrane, the glans penis and clitoridis and probably other parts of the integument highly endowed with sensibility. Within the conjunctiva, as described by Dogiel[1], they lie superficially placed within the connective tissue near the summit of the papillæ and folds, when such elevations exist, but always close beneath the epithelium. They vary considerably in size, often being small (.002–.004 mm.), but sometimes measuring from .05–.10 mm. in diameter. Usually a single nerve-fibre, exceptionally two or even more, enters each bulb, losing its medullary sheath as it pierces the thin fibrous capsule. Within the latter the nerve, now represented by the naked axis-cylinder, divides into from two to four branches, which, after describing several annular or spiral turns, give off varicose fibrils that undergo further division, the terminal threads forming a more or less intricate maze within the semifluid substance enclosed by the fibrous capsule.

[1] Archiv f. mik. Anat., Bd. xliv., 1895.

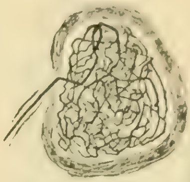
The Genital Corpuscles.—These endings, most numerous (from one to four to the square millimeter) in the deeper strata of the corium covering the glans penis and clitoridis, but occurring also in the neighboring parts of the genitalia, are of irregular oval or lobulated outline and from .02 to .35 mm. in diameter. They present the same general architecture as the end-bulbs, but are of larger size, possess a somewhat thicker capsule, and contain a more intricate interlacement of the terminal nerve-fibrillæ. The latter are derived from the subdivision of two or three medullated fibres that enter near the base of the corpuscle and are beset with varicosities and club-shaped terminal enlargements. The fibrous capsule, consisting of several connective tissue lamellæ possessing flattened fusiform nuclei, encloses the semifluid or granular interfibrillar substance in which the end-arborizations are embedded.

FIG. 870.



Genital corpuscle from integument of penis; nerve divides before piercing capsule and terminates in intricate end-windings. (*Dogiel.*)

FIG. 871.



Genital corpuscle from integument of human clitoris. × 350. (*Worthmann.*)

The Corpuscles of Meissner.—In man these are most numerous in the corium of the skin covering the flexor surface of the fingers and toes. They are also found in other regions possessing sensibility in a high degree, such as the lips, margin of the eyelid, nipple, penis and clitoris, as well as on the dorsum of the hand and foot and the radial surface of the forearm. On the volar surface of the distal phalanx of the fingers, where they occur in greatest numbers, some twenty are found to the square millimeter (Meissner). The corpuscles occupy the summit of the papillæ and ridges of the connective tissue stratum of the skin, and lie close beneath the cuticle, with their long axes perpendicular to the latter. In shape they are elongated irregular ellipsoids, often somewhat sinuous in outline, and in the larger papillæ may be joined at the deeper end with others to form a compound corpuscle. They are relatively large, being from .12–.18 mm. long and about one-third as wide. Depending upon the size, each corpuscle is supplied by one or more nerve-fibres which enter in the vicinity of the base, as the deeper end is called, and, on piercing the capsule and losing the medullary sheath, divide into a number of naked axis-cylinders. These pass across the corpuscle in parallel or spiral windings and are beset with fusiform and pyriform varicosities, similar enlargements marking the ends of the terminal threads. The entire fibrillar interlacement is embedded within a semifluid substance and enclosed by a thin nucleated fibrous capsule.

FIG. 872.

Corpuscle of Meissner lying within papilla of corium of skin from finger; only deeper layers of overlying epidermis are shown; *n*, entering nerve-fibre. × 270.

The Corpuscles of Ruffini.—These endings are also found within the skin, but at deeper levels, near and sometimes within the subcorium. They are of large size, sometimes measuring as much as 1.35 mm. in length, and of an elongated fusiform contour. The nerve-fibres, often two or more, which usually join the capsule on the side, less frequently near one end, retain the medullary sheath for some distance after penetrating the capsule and throughout

a number of bold curves and twistings. After the disappearance of their sheaths, the naked axis-cylinders undergo repeated divisions, the resulting fibrillæ becoming varicose and intertwined and ending in free terminal knob-like enlargements.

FIG. 873.

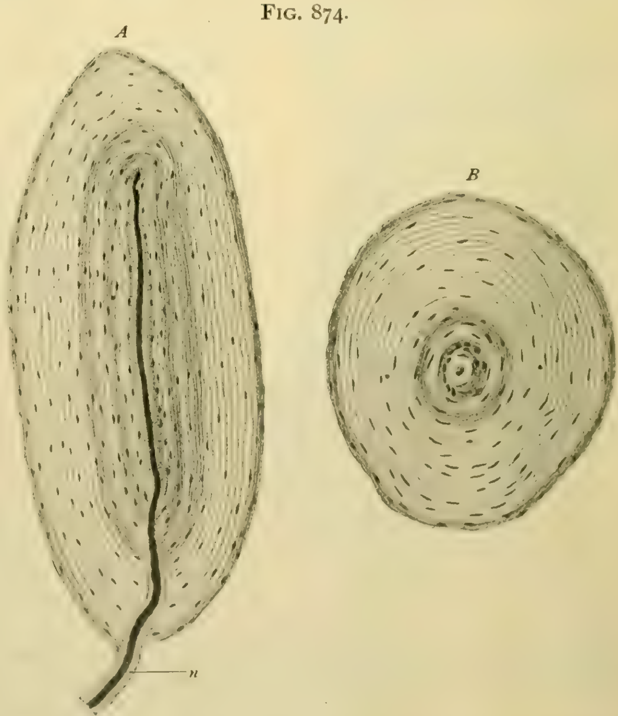
Cylindrical end-bulb from connective tissue layer of skin. × 180. (*Szymonowicz.*)

In contrast to the foregoing end-organs, in which the axis-cylinder subdivides into numerous terminal threads disposed as more or less elaborate intertwinings, a second group is distinguished by the possession of a thick *laminated capsule* that encloses a cylindrical core or *inner bulb* containing the slightly branched axis-cylinder. These endings, of which the Pacinian corpuscle is representative, are relatively large and ellipsoidal.

A transitional form, connecting them with the spherical end-bulbs, is presented by the **cylindrical end-bulbs of Krause.** These are found in various parts of the corium, the oral mucous membrane and between the bundles of striped muscle and of tendon. They are irregularly cylindrical in form, often more or less bent, and consist of a thin laminated capsule that encloses a core of semifluid substance in which lies the centrally placed axis-cylinder. The latter, after losing the medullary sheath on entering at the proximal end of the capsule, traverses the core without branching until near the distal pole, where it ends in a single or slightly subdivided terminal enlargement.

The Vater-Pacinian Corpuscles.—These structures, the most highly specialized sensory end-organs, are relatively large ellipsoidal bodies, from .5–1.5 mm. in length and about one-third as much in breadth, situated within the connective tissue in many parts of the body. In man they are found in the deeper layers of the connective tissue layer of the skin, especially on the palmar and plantar aspects of the fingers and toes, in the connective tissue in the vicinity of the joints, in tendons, in the sheath of muscles, in the periosteum and in the tunica propria of the serous membranes, the peritoneum, pleura and pericardium. They are particularly large in the mesentery of the cat, where they may be readily detected with the unaided eye as oval pearly bodies sometimes two millimeters or more in length.

FIG. 874.



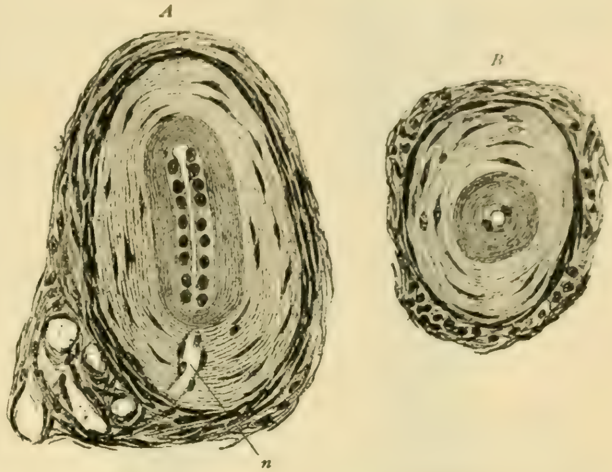
Vater-Pacinian corpuscles from skin of child's finger; *A*, longitudinal; *B*, transverse section; *n*, nerve entering capsule to reach inner bulb. × 185.

The most conspicuous part of the Pacinian body is the robust *capsule* that constitutes almost the entire bulk of the corpuscle and consists of from one to three dozen thin concentric lamellæ of fibrous tissue. The surfaces of the lamellæ are covered with endothelial plates whose nuclei appear as fusiform thickenings, along the concentric striæ of the corpuscle. The axis of the Pacinian body

is occupied by a *core* or *inner bulb* of semifluid substance in which the naked axis-cylinder is embedded.

On joining the proximal pole of the corpuscle, the fibrous (Henle's) sheath of the nerve-fibre blends with the outer lamellæ of the capsule, while the medullary coat is retained during the somewhat tortuous path of the fibre through the capsule as far as the core. Here the remaining envelope of the nerve-fibre disappears, the terminal part of its course, through the core, being as the naked axis-cylinder. At a variable distance but often just before gaining the distal pole of the core, the axis-cylinder divides into from two to four branches, each of which terminates in a slightly expanded end-knot. Sometimes shortly after penetrating the capsule, the nerve-fibre splits into two or more axis-cylinders which then share the common envelope of semifluid axial substance.

FIG. 875.



Corpuscles of Herbst from bill of duck; *a*, longitudinal, *b*, transverse section; *n*, nerve traversing lamellæ of capsule; axis-cylinder within core is surrounded by cells. × 360.

Similar end-organs, the **corpuscles of Herbst,** occur in the velvety skin covering the bill and in the tongue of water-fowl. They closely resemble the Pacinian bodies of mammals, but differ in being generally smaller, relatively broader, and in exhibiting a row of cubical cells within the core and around the axis-cylinder. These cells are regarded as corresponding to the large cells enclosing the tactile discs in the Grandry's corpuscles.

The **Golgi-Mazzoni corpuscles,** found in the subcutaneous tissue of the pulp of the fingers, are modifications of the ordinary Pacinian end-organs. They differ from the latter in possessing fewer lamellæ, a relatively larger core and a more branched axis-cylinder.

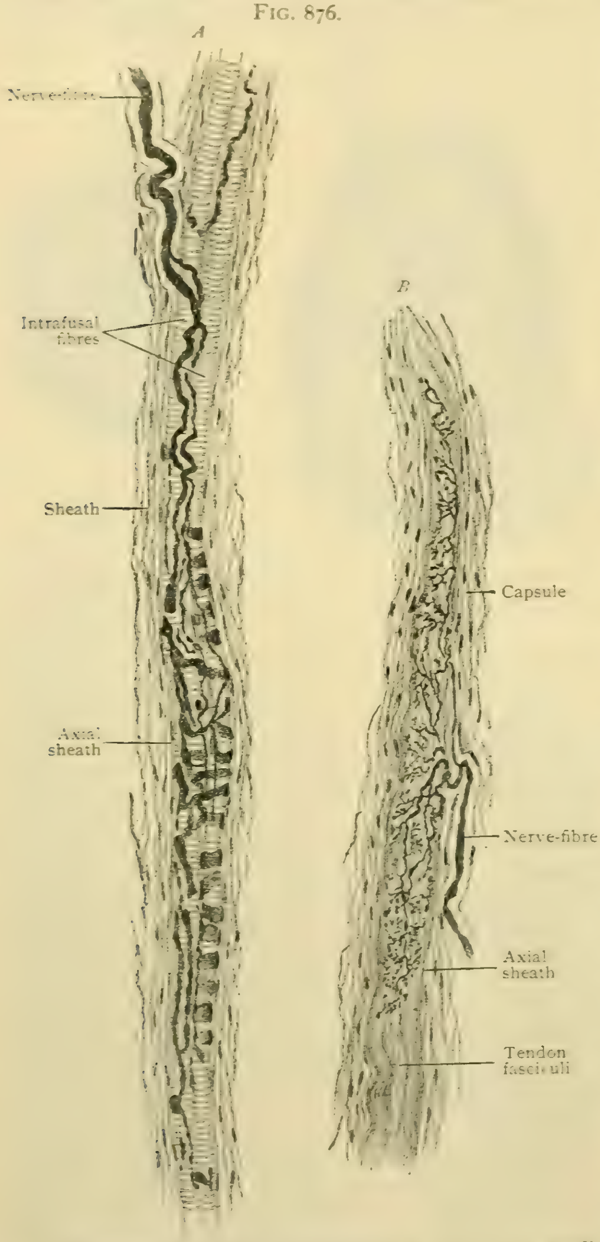
Neuromuscular Endings.—First described by Kölliker and by Kühne, although previously seen by Weissmann, these end-organs, often termed *muscle-spindles*, are now regarded as sensory endings that are probably concerned in affording impressions as to tension or "muscle-sense". They lie within the connective tissue separating the bundles of voluntary muscle-fibres and are long spindle-shaped structures, varying in length from 1–5 mm. or more and in width from .1–.3 mm. where broadest. They are widely distributed, being probably present in all the skeletal muscles, and are especially numerous in the small muscles of the hand and foot. They are uncertainly found, however, in the intrinsic muscles of the tongue and in the eye muscles, although within the tendons of the latter very similar (*neuro-tendinous*) end-organs have been demonstrated.

Each spindle consists of a *capsule*, composed of a half-dozen concentric layers of fibrous tissue, which encloses a group of usually from three to ten, but sometimes as many as twenty, striped muscle-fibres, medullated nerves, blood-vessels and interspersed connective tissue. These *intrafusal fibres*, as they are called, differ from those of the surrounding muscle in being much smaller in diameter and length, markedly tapering towards either end, more coarsely but less distinctly striated, and in possessing nuclei within the sarcous substance. The striations are not equally distinct in all parts of the fibres, being much less evident in the middle zone than towards the ends. The fibres are more numerous and of greater diameter in the equatorial region than near the poles of the spindle.

The intrafusal fibres collectively are surrounded by a thin special connective tissue envelope, the *axial sheath*, between which and the capsule lies the periaxial

lymph-space. Each spindle receives usually several medullated nerve-fibres, which, after incorporation of their sheaths of Henle with the capsule, pierce the latter at various points and proceed to the individual muscle-fibres. The terminal relations of the nerves to the intrafusal fibres have been studied by means of the newer methods especially by Ruffini, Huber and DeWitt and Dogiel. After repeated division during their course through the capsule and periaxial space, the nerve-fibres pierce the axial sheath, lose their medullary coat and terminate either as one or more ribbon-like branches that encircle the muscle-fibres in annular or spiral windings, or, after further subdivision, as branched telodendria in which the ultimate fibrils end in irregular spherical or pyriform enlargements.

FIG. 876.



A, neuromuscular ending; *B*, neurotendinous ending in longitudinal section, methylene-blue staining. × 260. (Drawn from preparation made by Professor Huber.)

Neurotendinous Endings.—These end-organs, described by Golgi and subsequently more fully investigated by Kölliker, Ciaccio, and Huber and DeWitt, in their general architecture resemble closely the sensory endings in muscle. They lie embedded within the interfascicular connective tissue and are usually found in the vicinity of the junction of muscle and tendon. Like the neuromuscular endings, the *tendon-spindles* are long fusiform structures, from 1.–1.5 mm. in length, surrounded by a fibrous capsule. The latter encloses a group of from eight to twenty *intrafusal tendon fasciculi*, which are smaller and apparently less mature than those of the surrounding tendon-tissue. The intrafusal fasciculi are invested by a fibrous axial sheath between which and the capsule lies a periaxial lymph-space.

On reaching the spindle, after repeated branching, the medullated nerve-fibres penetrate the capsule, with which their fibrous (Henle's) sheaths blend, and undergo further division. The medullary coat is lost after they pierce the axial sheath, the naked axis-cylinders breaking up into smaller fibrils that extend along the intrafusal fasciculi. The terminal ramifications, applied to the surface of the fasciculi, vary in details (Huber). Some arise as short lateral branches that partly encircle the fasciculi and end in irregular plate-like expansions, while others terminate between the smaller fasciculi.

THE CENTRAL NERVOUS SYSTEM.

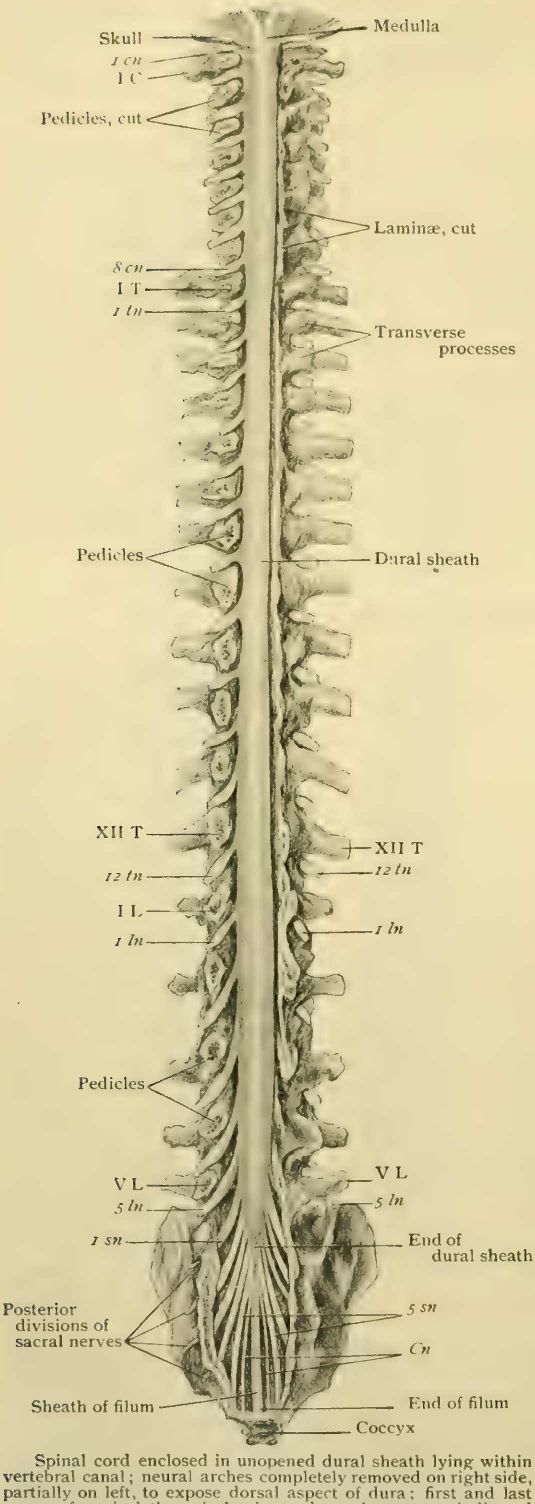
The central nervous system includes the spinal cord and the brain. In principle these parts are to be regarded as the walls of the primary *neural tube*, modified by unequal growth and expansion, which even after acquiring their definite relations enclose the remains of the canal, as represented by the system of ventricular spaces. In contrast to the spinal segment of the neural tube, which always remains a relatively simple cylinder, the spinal cord, the cephalic segment early differentiates into three *primary cerebral vesicles*, the anterior and posterior of which subdivide, so that five secondary brain-vesicles are present. Coincidently marked flexure of the cephalic segment occurs at certain points and in consequence this part of the neural tube becomes bent upon itself to such a degree that the axis of the anterior vesicle lies almost parallel with that of the spinal segment (Fig. 912). From the five *secondary divisions* of the flexed and sinuously bent cephalic segment of the neural tube are developed the fundamental parts of the brain in the manner presently to be described (page 1060), whilst from the relatively straight spinal segment proceeds the development of the spinal cord, in which process growth and differentiation convert the originally thin-walled tube into an almost solid cylinder, the minute central canal alone remaining as the representative of the once conspicuous lumen.

THE SPINAL CORD.

The spinal cord (**medulla spinalis**) is that part of the central nervous system, or cerebro-spinal axis, which lies within the vertebral canal. Its upper limit, where it becomes continuous with the medulla oblongata, is in a measure conventional, since there is no demarcation on the cord itself to indicate exactly its junction with the brain. Accurately considered, the superior limit of the cord may be assumed to correspond with the emergence of the uppermost root-fibres of the first spinal nerve which pass out between the atlas and the skull ; this level also corresponds to the lowest strands of the pyramidal decussation of the medulla oblongata and to the upper border of the posterior arch of the atlas. For practical purposes, however, the lower margin of the foramen magnum defines with sufficient accuracy the upper limit of the spinal cord. Below, the spinal cord terminates somewhat abruptly in a pointed end, the *conus medullaris*, that usually ends opposite the disc between the first and second lumbar vertebræ. The level to which the cord extends inferiorly, however, is subject to considerable variation, very rarely being as high as the middle of the body of the last thoracic vertebra (Moorhead), or as low as the upper border of the body of the third lumbar vertebra (Waring). In the female subject the spinal cord, although absolutely shorter than in the male, extends to a relatively lower level in the vertebral canal. Marked bending of the spine produces slight alterations in the position of the cord, during strong flexion an appreciable ascent of the lower end taking place. The relation of the cord to the vertebral canal varies at different periods. Until the third month of fœtal life the cord occupies the entire length of the canal, but subsequently, owing to the more rapid lengthening of the spine than of the spinal cord, the latter no longer reaches to the lower limit of the canal and, therefore, apparently rises, so that by the sixth fœtal month the lower end of the cord lies opposite the first sacral vertebra, and at birth terminates usually on a level with the body of the third lumbar vertebra.

Measured from its upper conventional limit to the lower end of the conus medullaris, the spinal cord in the adult male has an average length of 45 cm. (17¾ in.), and in the female of 43.7 cm. (17¼ in.), in both sexes the proportion of the length of the cord to that of the presacral spine being approximately as 64 : 100 (Ziehen). The cord-length bears no constant relation to stature, although in a general way tall individuals may possess long cords. The weight of the spinal cord, stripped of its membranes and nerves, is something less than 30 grammes (1 oz.), or about 1-2000 of the body-weight. Its proportion to the weight of the brain is 1 : 43. When fresh the spinal cord possesses a soft cheesy consistence and a specific gravity of 1035.

FIG. 877.



Spinal cord enclosed in unopened dural sheath lying within vertebral canal; neural arches completely removed on right side, partially on left, to expose dorsal aspect of dura; first and last nerves of cervical, thoracic, lumbar and sacral groups are indicated by Italic figures; corresponding vertebræ by Roman numerals.

The Membranes of the Cord.—The spinal cord, together with the roots of the thirty-one pairs of spinal nerves, lies within the vertebral canal enclosed by three protecting membranes, or meninges, which, from without inward, are (1) the *dura mater*, (2) the *arachnoidea*, and (3) the *pia mater*, all of which are directly continuous through the foramen magnum with the corresponding coverings of the brain. The external sheath, or *theca*, formed by the dura, is a robust fibro-elastic tubular envelope, much longer and considerably wider than the cord, that does not lie against the wall of the vertebral canal, but is separated by an interval containing thin-walled plexiform veins and loose fatty connective tissues (Fig. 879).

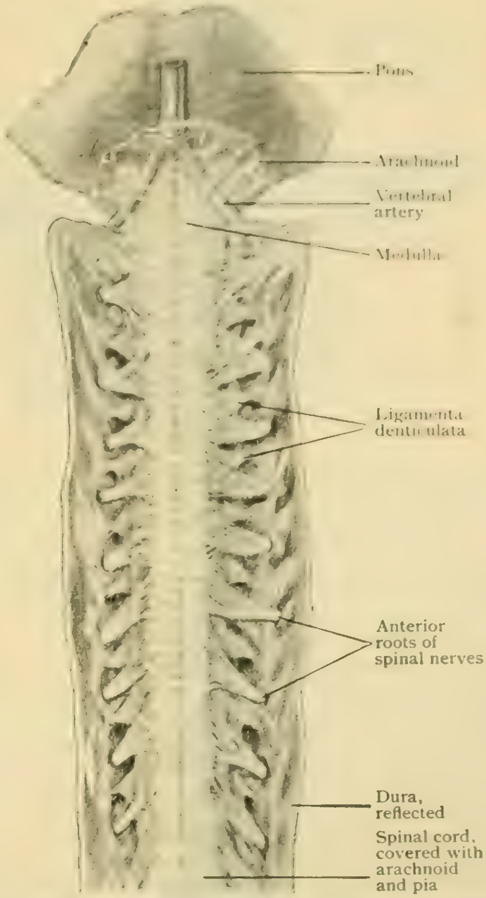
The **dural sheath**, about .5 mm. in thickness, extends to the level of the second sacral vertebra and is, therefore, considerably longer than the spinal cord. The part of the sac not occupied by the cord encloses the longitudinal bundles of root-fibres, that pass obliquely to the levels at which the corresponding nerves leave the vertebral canal, and a fibrous strand, the *filum terminale*, prolonged from the cord to the lower end of the spine.

The **pia** constitutes the immediate investment of the cord and supports the blood-vessels destined for the nutrition of the enclosed nervous cylinder. The pial sheath is composed of an outer fibrous and an inner vascular layer, the connective tissue of the latter accompanying the blood-vessels into the substance of the cord.

The **arachnoid**, a delicate veil-like structure made up of interlacing bundles of fibro-elastic tissue, lies between the other two membranes and invests loosely the inner surface of the dura and closely the outer surface of the pia. It effectually subdivides the considerable space between the external and internal sheaths into two compartments, the one beneath the dura, the *subdural space*, being little more than a capillary cleft filled with modified lymph, and the other, the *subarachnoid space*, between the arachnoid and

the pia, containing the *cerebro-spinal fluid*. The spinal cord, therefore, hangs suspended within the tube of dura, surrounded by a cushion of fluid—an arrangement well adapted to insure the nervous cylinder against the injurious effects of shocks and of undue pressure during changes in the position of the spine. Both spaces, but particularly the subarachnoid, are crossed by fibrous trabeculæ and thus imperfectly subdivided into secondary compartments, all of which are lined with endothelium.

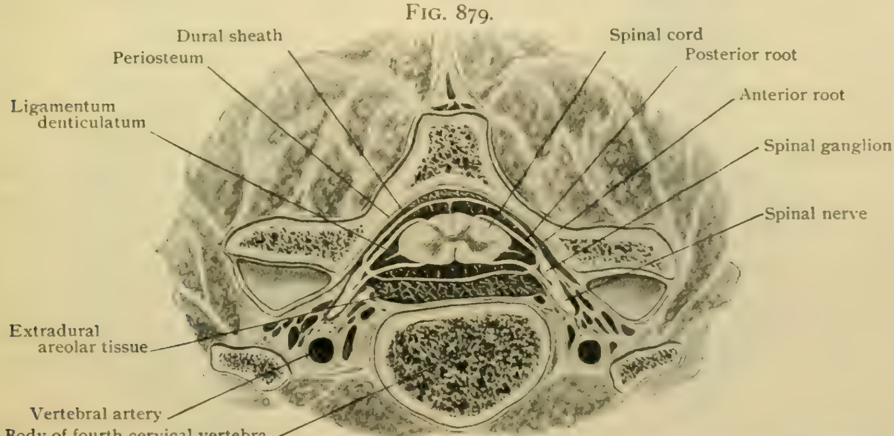
FIG. 878.



Upper part of spinal cord within dural sheath, which has been opened and turned aside; ligamenta denticulata and nerve-roots are shown as they pass outward to dura.

The spinal cord is fixed within the loose dural sheath not only by the root-fibres of the spinal nerves that pass between the cord and the outer envelope, but also by two lateral fibrous bands, the *ligamenta denticulata*, that are continuous with the pia along the cord, one on each side. Mesially they are attached between the anterior and posterior root-fibres and externally to the inner surface of the dura by the tips of pointed processes, about twenty-one in all, that stretch across the subarachnoid space, which they imperfectly divide into a general anterior and a posterior compartment. The ligaments, covered by prolongations of the arachnoid, extend the entire length of the cord, the first process being attached to the margin of the foramen magnum, immediately above the vertebral artery as it pierces the dura. The succeeding ones meet the dura between the pairs of spinal nerves, the lowest process lying between the last thoracic and the first lumbar nerve. In the cervical and thoracic region, a median fibrous band, the *septum posticum*, connects the posterior surface of the cord

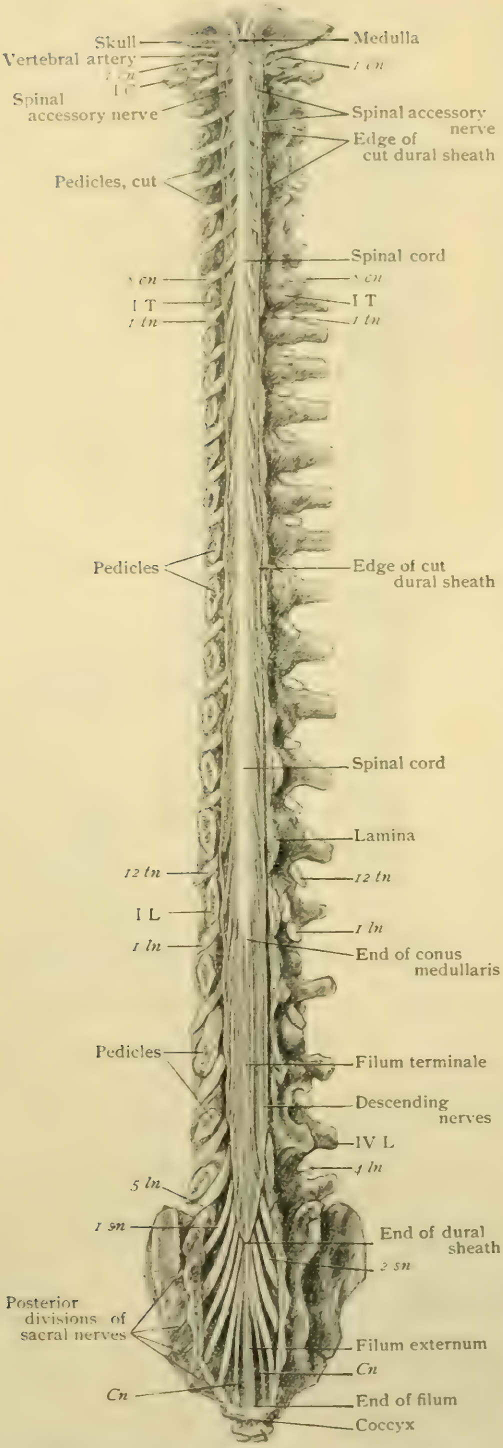
FIG. 879.



Transverse section of vertebral canal at level of fourth cervical vertebra, spinal cord in position.

with the dura and partially subdivides the subarachnoid space. Lower, this partition,

FIG. 880.



Posterior wall of vertebral canal has been removed and dural sheath opened to expose spinal cord and dorsal roots of attached nerves; *1 cn*, I C, first cervical nerve and vertebra respectively; *Cn*, coccygeal nerves.

which may transmit blood-vessels, is imperfect or altogether absent. As they cross the subarachnoid space the bundles of root-fibres of the spinal nerves are enclosed by prolongations of the pia and arachnoid. These sheaths are retained by the nerves for only a short distance after the latter receive an additional investment from the dura as they leave the vertebral canal. The dural sheath becomes continuous with the epineurium of the spinal nerves.

The Cord-Segments.—Although no suggestion of such subdivision is to be seen as constrictions on its surface, in principle the spinal cord consists of a series of segments, each of which gives origin to the *anterior* (motor) and receives the *posterior* (sensory) *root-fibres* of one pair of spinal nerves. These nerves, usually thirty-one pairs in number, are classified as eight *cervical*, twelve *thoracic*, five *lumbar*, five *sacral*, and one *coccygeal*. Corresponding to the attachment of the nerves the cord is conventionally divided into *cervical*, *thoracic*, *lumbar*, and *sacral regions*. Of the entire length of a cord measuring 43 cm., approximately 10 cm., or about 23.5 per cent., belonged to the cervical region; 24 cm., or 55.5 per cent., to the thoracic; 6 cm., or 14 per cent., to the lumbar; and 3 cm., or 7 per cent., to the sacral region.

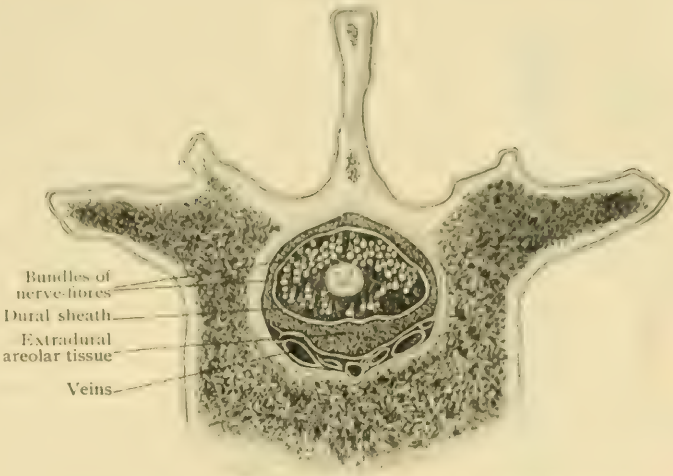
The spinal nerves are attached to the lateral surfaces of the cord by fan-shaped groups of anterior and posterior root-fibres that are gathered into compact strands as they converge to form a common trunk (Fig. 884). The portion of the spinal cord with which the root-fibres of a spinal nerve are connected constitutes its **cord-segment**, the limits of which lie in the interval separating the extreme fibres of the nerve and those of the adjacent nerves. In the thoracic cord these intervals are very evident, since the segments are relatively long; in the cervical and lumbar regions, on the contrary, the groups of root-fibres are so crowded that they form almost unbroken rows.

The length of the individual cord-segments varies; thus, according to the measurements of Lüderitz, those of the cervical region, are from 11–13.5 mm.;

those of the thoracic region from 12–26 mm., the longest belonging to the V–VII thoracic nerves; those of the lumbar region rapidly decrease from 15.5–5.5 mm., followed by a more gradual diminution to less than 4 mm. in the sacral region.

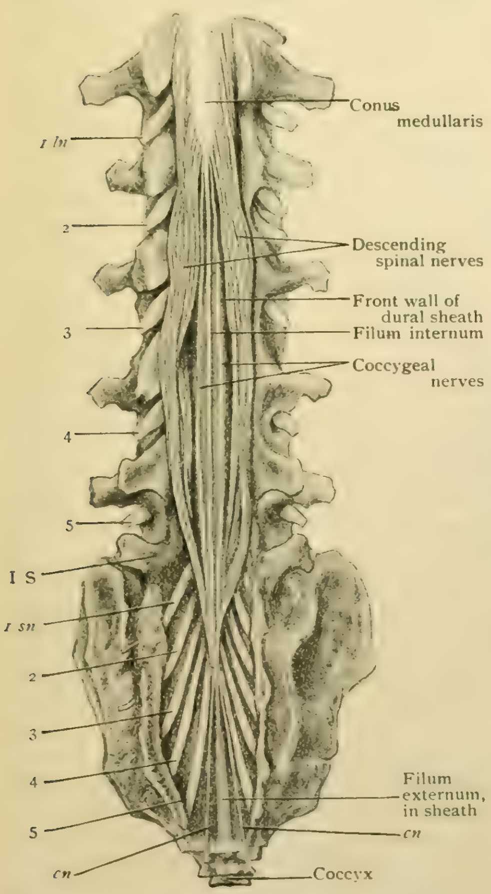
In consequence of the disproportion between the length of the spinal cord and that of the vertebral canal, the discrepancy between the level at which the nerves are attached to the cord and that of the intervertebral foramina through which they leave the canal becomes more marked towards the lower end of the series. The growth of the cord, however, is not uniform since, as shown by Pfitzner, during the later years of childhood elongation of the thoracic region occurs to such an extent that this part of the cord once more equals, if indeed not exceeds, the corresponding portion of the spine. While the cervical cord keeps fairly abreast the cervical portion of the vertebral column, the lumbar and sacral segments are left far behind. The results of these changes are seen in the course of the root-fibres, which in the neck, below the third nerve, run somewhat downward to their points of emergence, and in the thoracic region pass more horizontally, while those of the lumbar and sacral nerves descend almost vertically for a considerable distance—in the case of the last sacral nerve 28 cm. (Testut)—before reaching their appropriate levels.

FIG. 881.



Transverse section of vertebral canal, at level of middle of first lumbar vertebra; spinal cord (conus medullaris), surrounded by nerve-bundles, is seen within dural sheath.

FIG. 882.



End of spinal cord with roots of lower nerves descending in cauda equina to gain their respective foramina; *1–5 ln*, *1–5 sn*, *cn*, lumbar, sacral and coccygeal nerves.

The large and conspicuous leash of descending root-fibres, seen upon opening the dural sheath, constitutes the **cauda equina,** in the midst of which the glistening silvery **filum terminale** is distinguishable. It is evident, therefore, that in most cases the level of the cord-segment and that of the vertebra bearing the same designation do not correspond. Likewise, it must be remembered that, although in general the spinal nerves are named in accordance with the vertebræ immediately below which they escape, in the neck there are eight cervical spinal nerves and only seven vertebræ, the first or suboccipital nerve emerging between the atlas and the skull, and the eighth between the last cervical and first thoracic vertebra; hence, except the last one, they correspond with the vertebra below.

Form of the Cord.—After removal of its membranes and the root-fibres, the spinal cord is seen to differ from a simple cylinder in the following respects. It is somewhat flattened in the antero-posterior direction, so that the sagittal diameter is always less than the transverse diameter, and its outline in cross-sections, therefore, is not circular but more or less oval; its width is not uniform on account of two conspicuous swellings that are associated with the origin and reception of the large nerves supplying the limbs. The upper or **cervical enlargement** (**intumescentia cervicalis**) begins just below the upper end of the cord and ends opposite the second thoracic vertebra, having its greatest expansion at the level of the fifth and sixth cervical vertebræ, where the sagittal diameter is about 9 mm. and the transverse from 13–14 mm. The lower or **lumbar enlargement** (**intumescentia lumbalis**) begins opposite the tenth thoracic vertebra, slightly above the origin of the first lumbar nerve, and fades away in the **conus medullaris** below. It appears very gradually and reaches its maximum opposite the twelfth thoracic vertebra, where the cord has a sagittal diameter of 8.5 mm. and a transverse diameter of from 11–13 mm. (Ravenel). The lumbar enlargement is associated with the great nerve-trunks supplying the lower limbs. The intervening part of the thoracic region is the smallest and most uniform portion of the cord and is almost circular in outline. Where least expanded, opposite the middle of the thoracic spine, the cord measures 8 mm. in its sagittal and 10 mm. in its transverse diameter. These enlargements appear coincidently with the formation of the limbs, are relatively small during fœtal life, and acquire their full dimensions only after the limbs have attained their definite growth. In a general way, a similar relation between the size of the enlargements and the degree of development of the limbs is observed in the lower animals.

FIG. 883.

Spinal cord denuded of membranes and nerves, showing proportions of its length contributed by different regions and position and relative size of enlargements, as viewed from before; semidiagrammatic, based on measurements; one-third actual size.

At the tip of the conus medullaris the spinal cord is prolonged into a delicate tapering strand, the **filum terminale,** that consists chiefly of fibrous tissue continued from the pia mater and invested by arachnoid. It extends to the bottom of the pointed and closed end of the dural sac, which it pierces at the level of the second sacral vertebra and, ensheathed by a prolongation of dura (*vagina terminalis*), as the *filum terminale externum*, proceeds downward through the lower end of the sacral canal for a distance of about 8 cm. (3⅛ in.), finally to be attached to the periosteum covering the posterior surface of the coccyx. The part within the dural sac, the *filum terminale internum*, is about 16 cm. (6¼ in.) in length and surrounded by the nerve-bundles of the cauda equina (Fig. 882), from which it is readily distinguished by its glistening silvery appearance.

The upper half or less of the internal filum contains the terminal part of the central canal of the spinal cord walled by a thin and variable layer of nervous substance in which small nerve-cells are usually present. The minute bundles of nerve-fibres often found adhering to the filum, which sometimes may be followed to and even through the dural sheath, are regarded by Rauber as representing one or two additional (second and third) coccygeal nerves, homologous with the caudal nerves of the lower animals.

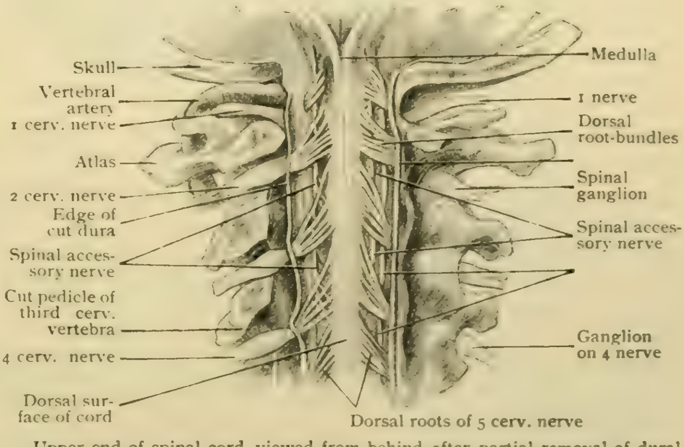
The Columns of the Cord. Inspection of the surface and particularly of cross-sections of the spinal cord (Fig. 885) shows the latter to be partially divided into a symmetrical right and left half by a median cleft in front and a partition in the mid-line behind. The cleft, the **anterior median fissure** (**fissura mediana anterior**) extends the entire length of the cord, and is continued on the upper part of the filum terminale. It is narrow, from 2–3.5 mm. in depth, penetrating for less than one-third of the ventro-dorsal diameter of the cord, and occupied by a process of pia mater. Along its floor, which lies immediately in front of the white commissure, it is frequently deflected to one side of the mid-line and presents a slight expansion.

The separation into halves is completed by the **posterior median septum** (**septum medianum posterius**), the so-called *posterior median fissure*. With the exception of a shallow groove in the upper cervical cord, the lumbar enlargement and the conus medullaris, no fissure exists, but in its place a dense partition extends from the posterior surface to the middle of the interior of the cord, ending in close relation to the gray commissure.

The character of the septum is a subject of dispute, according to some anatomists consisting exclusively of condensed neuroglia, while others regard it as composed of pial tissue blended with the neuroglia and, therefore, of both mesoblastic and ectoblastic origin. The latter view is substantiated by the mode of development of the posterior septum, the immature pial covering of the developing blood-vessels being imprisoned within and fused with the neurogliar partition derived from the expanding dorsal halves of the developing cord (page 1050). The application of differential stains also demonstrates the composite nature of the septum.

Each half of the spinal cord is further subdivided by the lines along which the root-fibres of the spinal nerves are attached. The root-line of the dorsal (sensory) fibres is relatively straight and narrow, and marked by a slight furrow, the **postero-lateral sulcus** (**sulcus lateralis posterior**) that lies from 2.5–3.5 mm. lateral to the posterior septum and is evident even on the intersegmental intervals where the root-fibres are practically absent. The **ventral root-line,** marking the emergence of the anterior (motor) fibres, is much less certain, since the bundles of fibres of the individual nerves do not emerge in the same vertical plane, but overlie one another to some extent, so that each group occupies a crescentic area, whose greatest width corresponds in a general way with that of the subjacent ventral horn of gray matter. The anterior root-line, which lies from 2–4 mm. lateral to the median fissure, is neither indicated by a distinct furrow nor continuous.

FIG. 884.



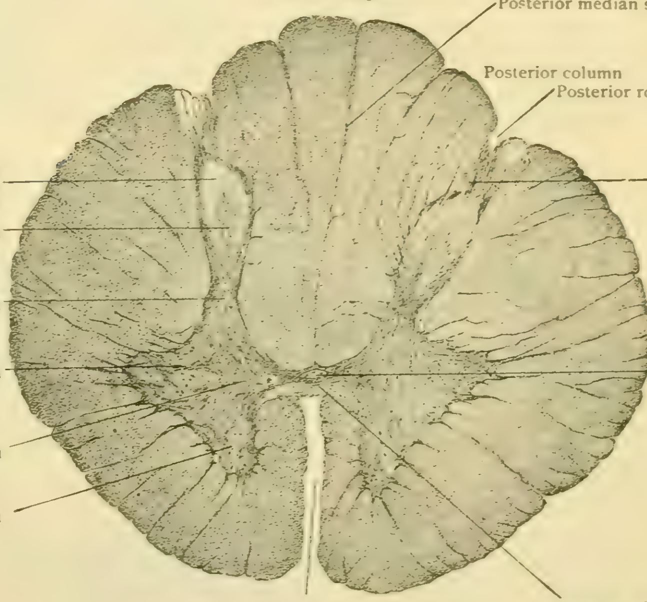
Upper end of spinal cord, viewed from behind after partial removal of dural sheath; cord-segments are indicated by groups of converging bundles of posterior root-fibres; spinal ganglia are seen lying within the intervertebral foramina; spinal accessory nerve is seen ascending on each side.

In this manner two longitudinal tracts, the **posterior columns** (**funiculi posteriores**) are marked off between the posterior median septum and the sulci of the posterior root-lines. These columns include something less than one-third of the semi-circumference of the cord, and are about 6 mm. in width in the thoracic cord and 8 mm. and 7 mm. in the cervical and lumbar enlargements respectively. The tracts included between the dorsal and ventral root-lines constitute the **lateral columns** (**funiculi laterales**) and those between the ventral root-lines and anterior median fissure are the **anterior columns** (**funiculi anteriores**). Such subdivision into anterior and lateral

columns is, however, largely artificial, since neither superficially nor internally is there a definite demarcation between these tracts. They may be, therefore, conveniently regarded as forming a common *antero-lateral column*, that on each side embraces something more than two-thirds of the semicircumference of the cord. In the lower cervical and upper thoracic cord, each posterior column is subdivided by a shallow furrow that lies from 1.5–2 mm. lateral to the posterior medium septum. This, the **paramedian sulcus** (sulcus intermedius posterior), corresponds in position with the peripheral attachment of a radial septum of neuroglia that penetrates the white matter for a variable distance, sometimes almost as far as the gray matter, and subdivides the posterior column into two unequal tracts, of which the inner and smaller is the **postero-median column** (fasciculus gracilis), or **column of Goll**, and the outer and larger is the **postero-lateral column** (fasciculus cuneatus), or **column of Burdach.**

The Gray Matter.—Inspection of the transversely sectioned spinal cord, even with the unaided eye, shows it to be composed of an irregular core of gray substance enclosed by a mantle of white matter. Within each half of the cord the gray

FIG. 885.



Transverse section of thoracic cord, showing disposition of gray and white matter and division of latter into anterior, lateral and posterior columns. × 13.

matter forms a comma-shaped area, the broader end of which lies in front and the narrower behind, with the concavity directed laterally. The convex surfaces of the tracts of the two sides, which look towards each other and the mid-line, are connected by a transverse band of gray matter, the **gray commissure** (commissura grisea) that extends across the mid-line, usually somewhat in advance of the middle of the sagittal diameter, and encloses the minute **central canal** of the cord. By this canal the connecting band, or central gray matter, is divided into a dorsal and a ventral part, the *posterior* and the *anterior gray commissure*, which lie behind and in front of the tube respectively.

While the posterior median septum reaches the dorsal surface of the gray commissure, the ventral margin of the latter is separated from the anterior median fissure by an intervening bridge of white matter, the **anterior white commissure** (commissura anterior alba) which connects the anterior columns of the cord and provides an important pathway for fibres passing from one side to the other. A zone of modified neuroglia immediately surrounding the central canal is known as the **substantia gelatinosa centralis** (substantia grisea centralis).

Each crescent of gray matter is divisible into three parts—the ventral and the dorsal extremity, that project beyond the transverse gray commissure and constitute the *anterior* and *posterior horns* or cornua of the gray matter (**columnae griseae**), and the *intermediate portion* (**pars intermedia**) that connects the cornua and receives the commissure. The two horns differ markedly from each other and, although varying in details in different levels, retain their distinctive features throughout the cord.

The **anterior cornu** (**columna grisea anterior**) is short, thick and rounded, and separated by a considerable layer of white matter from the surface of the cord, through which the ventral root-fibres proceed to their points of emergence in the root-areas. The blunt tip of the anterior horn is known as the *caput cornu*, and the dorsal portion by which it joins the commissure and the pars intermedia as the *basis cornu*.

The **posterior cornu** (**columna grisea posterior**) presents a marked contrast in being usually relatively long, narrow and pointed, and in extending peripherally almost to the postero-lateral sulcus. The tip or *apex* of the dorsal horn is formed of a Λ-shaped stratum of peculiar character, the **substantia gelatinosa Rolandi,** that appears lighter in tint (Fig. 885) and somewhat less opaque than the subjacent and broader portion of the horn, *caput cornu*, which it covers as a cap. More ventrally the posterior horn is usually somewhat contracted, to which portion the term, *cervix cornu* (**cervix columnae posterioris**) is applied. In the lower thoracic cord, however, this constriction is replaced by a slight bulging located on the mesial side of the junction of the posterior cornu with the gray commissure. This enlargement corresponds to the location of a longitudinal group of nerve-cells constituting the column of Clarke.

The fairly sharp demarcation between the gray and white matter is interrupted along the lateral border of the crescent by delicate prolongations of gray matter into the surrounding lateral column (Fig. 888). The subdivisions of these processes unite to form a reticulum of gray matter, the meshes of which are occupied by longitudinally coursing nerve-fibres, the whole giving rise to an interlacement known as the *processus* or *formatio reticularis*. Although to some extent present in the greater part of the cord, this structure is most marked in the upper cervical region, where it exists as a conspicuous net-work filling the recess that indents the lateral border of the pars intermedia and the neck of the posterior horn of the gray crescent. In the thoracic and upper parts of the cervical cord, therefore in regions in which the enlargements are wanting, the formatio reticularis is condensed into a compact process of gray matter that is directed outward (Fig. 885) and known as the **lateral cornu** (**columna lateralis**).

FIG. 886.

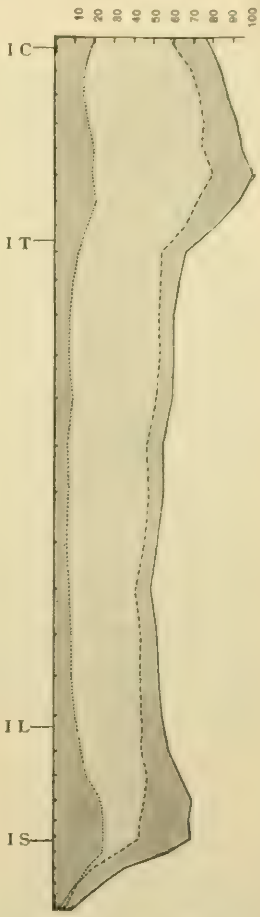


Diagram showing amount of gray and white matter in relation to entire area of cord, and relative lengths of cord-segments; the latter are indicated by divisions on left margin of figure—I C, I T, I L, I S, first segment of cervical, thoracic, lumbar and sacral regions respectively; dark zone next left border represents the gray matter, light zone the white matter, outer dark zone the entire area of cord. (*Donaldson.*)

Taken as a whole, the gray matter, which in cross-sections appears as the H-shaped area formed by the two crescents and the commissure, constitutes a continuous column, whose irregular contour depends not only upon the peculiar disposition of the gray matter, but also upon the variations in its amount at different levels of the cord. Thus, at the level of the third cervical nerve the gray matter constitutes somewhat more than one-fourth of the entire area of the cord; at that of the seventh nerve about one-third, while in the thoracic region, between the second and eleventh nerves, it is reduced to about one-sixth. At the last thoracic nerve it again forms one-fourth, and at the third and fifth lumbar two-fifths and three-fifths respectively. In the sacral cord the relative amount of gray matter increases until, at the level

of the last sacral nerve, it reaches three-fourths. The absolute amount of gray matter is greatest within the cervical and lumbar enlargements of the cord, where it is directly related to the large nerves supplying the limbs. On comparing the tracts of white matter and the gray column it follows that while in the lower third of the lumbar cord these are of approximately equal area, below this level the gray matter exceeds the white. In the remaining regions, on the other hand, the white matter predominates, in the greater part of the thoracic cord exceeding the gray from four to five fold and in the cervical cord being from two to three times greater.

The Central Canal.—Where well represented, the central canal (**canalis centralis**), the remains of the once conspicuous neural tube, appears as a minute opening in the gray commissure, about .2 mm. in diameter and barely visible with the unaided eye. In the child it extends the entire length of the cord and, below, ends blindly in the upper half of the filum terminale. Above, it opens into the lower end of the fourth ventricle, from which it is prolonged downward through the lower half of the medulla oblongata into the spinal cord. In not over one-fifth of adult subjects, however, is the canal retained as a pervious tube throughout the cord, its lumen usually being partially or completely obliterated for longer or shorter stretches, the lumen last disappearing in the lower part of the cord. Within the conus medullaris, the central canal regularly exhibits an expansion, the **sinus terminalis**, that begins below the origin of the coccygeal nerve and extends caudally for from 8–10 mm., with a maximum frontal diameter of 1 mm. or over.

The obliteration of the central canal, complete in about 50 per cent. of subjects beyond middle life (Schulz), is to be regarded as a physiological accompaniment of advancing age. It is effected by displacement and proliferation of the ependyma-cells lining the canal, in conjunction with ingrowth of the surrounding neurogliar fibres (Weigert). The form of the canal, as seen in cross-sections, is very variable and uncertain owing to the changes incident to the use of hardening fluids. In a general way when well preserved the lumen is round or oval and smallest in the thoracic region ; in some places, as in the upper cervical cord and in the lumbar enlargement, it is larger and often appears pentagonal in outline, whilst in others the calibre may be reduced to a sagittal slit. The position of the central canal varies at different levels in relation to the ventral and dorsal surfaces of the cord. In the middle of the lumbar region it occupies approximately the centre of the cord, but above, in the thoracic and cervical segments, it lies much nearer the ventral than the dorsal surface, while below it gradually approaches the dorsal surface, but always remains closed.

Mention may be made of a remarkable structure named *Reissner's fibre*, after its discoverer, that as a longitudinal thread of great delicacy lies free within the central canal of the cord and the lower ventricle of the brain, extending from the cavity of the mesencephalon above to the lowest part of the cord-canal below. The interpretation of this structure as an artefact, which considering its extraordinary position is most natural, seems untenable in view of the positive testimony, confirming its existence as a preformed and true structure in many vertebrates, given by several subsequent observers and especially by Sargent. According to Dendy and to Nicholls,[1] the fibre is concerned in automatically regulating flexion of the body, by transmitting to the brain stimuli due to changes in tension.

MICROSCOPICAL STRUCTURE OF THE SPINAL CORD.

The three chief components of the spinal cord—the nerve-cells, the nerve-fibres and the neuroglia—vary in proportion and disposition in the white and gray matter. It is, therefore, desirable to consider the general structure of the cord before describing its detailed characteristics at different levels.

The Gray Matter.—The most distinctive elements of the gray matter are the *multipolar nerve-cells* which lie embedded within a complex sponge-like matrix formed by the various processes—dendrites, axones and collaterals—from other neurones, the supporting neuroglia and the blood-vessels. In two localities—immediately around the central canal and capping the dorsal cornu—the gray matter varies in its appearance and constitution and exhibits the modifications peculiar to the central and Rolandic substantia gelatinosa, the details of which call for later description (page 1034).

The **nerve-cells of the anterior horn** are multipolar, in cross-sections the cell-bodies appearing irregularly polygonal and in longitudinal sections fusiform in out-

[1] Anatomischer Anzeiger, Bd. xl., 1912.

line. They may vary from .065–.135 in diameter, unless unusually small, when they measure from .030–.080 mm. (Kölliker). In a typical example, as represented by one of the ventral **radicular cells** giving origin to anterior root-fibres, from three to ten dendritic processes radiate in various planes, divide dichotomously with decreasing width and finally end in terminal arborizations. In contrast to the robust dendrites beset with spines, the axone is smooth, slender and directly continuous with the axis-cylinder of a root-fibre of a spinal nerve and unbranched, with the exceptions of delicate lateral processes that are given off almost at right angles. These processes, the collaterals, arise at a variable distance from the cell-body, but usually close to the latter and always before leaving the gray matter. They repeatedly divide and follow a recurrent course within the anterior horn. After appropriate staining the cytoplasm of the nerve-cells exhibits conspicuous accumulations of the deeply staining tigroid substance that lie within the meshes of the reticulum formed by delicate neurofibrillæ, which not only occupy the cell-body but also extend into the various processes. The fibrillæ, however, do not pass beyond the limits of the neurone to which they belong (Retzius). Each nerve-cell possesses a spherical or ellipsoidal nucleus, from .010 to .020 mm. in its greatest diameter, which is enclosed by a distinct nuclear membrane and usually contains a single nucleolus, exceptionally two or three. Within the cytoplasm an accumulation of brownish-yellow pigment granules is usually present near one pole, often in the vicinity of the implantation cone from which the axone springs.

FIG. 887.

Portion of anterior cornu of gray matter, showing multipolar nerve-cells. × 120.

In addition to the conspicuous ventral *radicular cells* above described, the anterior horn contains other nervous elements, some of which, the *commissural cells*, send their axones through the anterior commissure to the opposite half of the cord, while the axones of others, the *strand-cells*, pass into the columns of white matter of the same, less frequently opposite, side.

The **commissural cells**, which with few exceptions occupy the median portion of the anterior horn, resemble in size and contour the radicular cells, but differ from the latter in possessing smaller nuclei. The majority of the dendrites are directed towards the inner part of the ventral cornu, but some pass into the gray commissure and a few end within the adjacent white matter. The axones traverse the anterior white commissure to gain the ventral column of the opposite side, in which they either divide T-like into ascending and descending fibres, or undivided turn brainward.

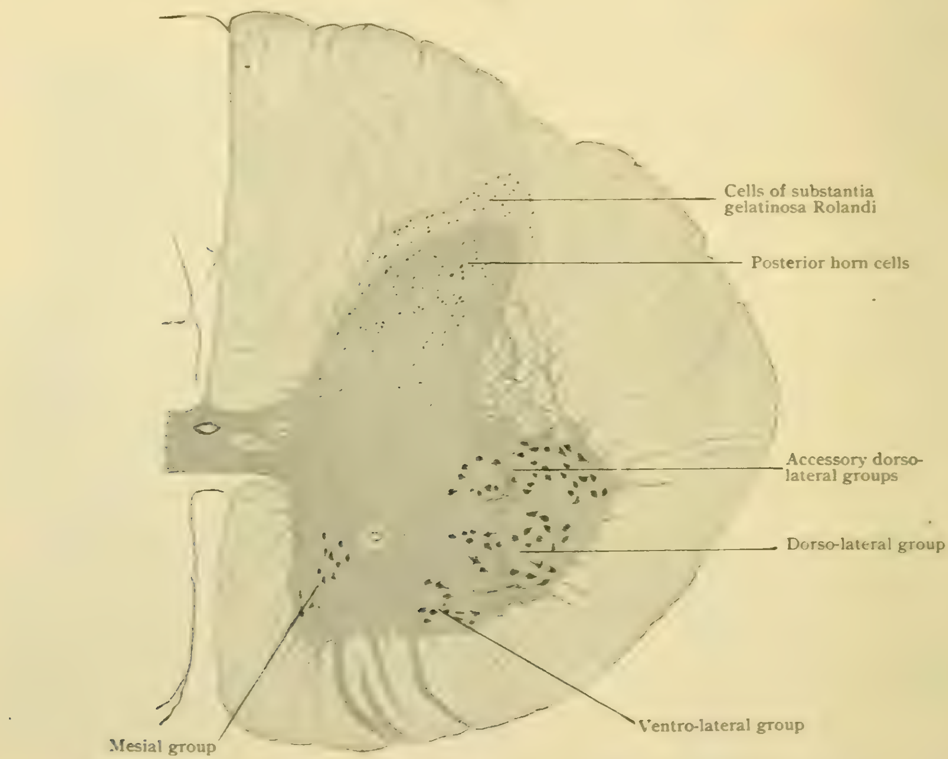
The **strand cells**, variable in form and generally smaller than the root-cells, are only sparingly represented in the anterior horn. They are distinguished by the course of their axones, which usually pass to the anterior column of the same side. In some cases, however,

the axone divides into two, rarely three, fibres, one of which crosses by way of the anterior white commissure to the opposite ventral column, while the other passes to the ventral column of the same side.

As well seen in cross-sections, although the nerve-cells of the anterior horn are widely scattered they are not uniformly distributed through the gray matter, but are collected into more or less definite groups that recur in consecutive sections. It is evident, therefore, that the cell-groups are not limited to a single plane, but are continuous as longitudinal tracts or columns for longer or shorter stretches within the core of gray matter of the cord.

The **grouping of the nerve-cells** of the anterior horn includes two general collections, a *mesial group*, containing many commissural cells, and a *lateral group* composed chiefly of ventral radicular cells. These collections, however, vary in extent and definition in different parts of the cord and, where well marked, are often

FIG. 888.



Transverse section of lower cervical cord, showing grouping of nerve-cells; Nissl staining. × 20.

made up of more than a single aggregation of cells. This feature is particularly evident in the lateral collection, in which an anterior and a posterior subdivision are recognized as the *ventro-lateral* and the *dorso-lateral group* that occupy the corresponding angles of the anterior horn. The mesial collection, situated within the ventral angle, is likewise, but much less clearly, divisible into a *ventro-mesial* and a *dorso-mesial group*, of which the latter is variable and at many levels wanting. In a general way the pronounced presence of these cell-groups influences the outline of the anterior horn, so that corresponding projections of the gray matter mark their position. This relation is conspicuously exemplified in the cervical and lumbo-sacral enlargements, in which the presence of large lateral cell-groups is directly associated with a marked increase in the transverse diameter of the anterior horn. Conversely, when these cell-columns become smaller or disappear, the corresponding elevations on the surface of the anterior horn diminish or are absent. Owing to such variations the contours of the gray core are subject to constant and sometimes abrupt change.

The **ventro-median cell-column** is the most constant, since, as emphasized by the painstaking studies of Bruce,[1] it is interrupted only between the levels of the fifth lumbar and first sacral nerve in its otherwise unbroken course through the length of the cord, as far as the level of the fifth sacral nerve. An augmentation of this tract in the fourth and fifth cervical segments is probably associated with the spinal origin of the phrenic nerve (Bruce).

The **dorso-mesial cell-column** is much less constant, being represented only in the thoracic region, in a few cervical segments and at the level of the first lumbar nerve. In agreement with van Gehuchten and others, Bruce regards the continuity of the mesial group as presumptive evidence of its close relation to the dorsal extensor muscles of the trunk.

The **ventro-lateral cell-column** appears first at the level of the fourth cervical nerve, increases rapidly in the succeeding segments and fades away at the lower part of the eighth cervical segment. It reappears in the lumbar enlargement, reaching its maximum at the level of the first sacral nerve and, diminishing rapidly through the upper part of the second, disappears before the third sacral segment is reached.

The **dorso-lateral cell-column**, in places the most conspicuous collection of the anterior horn, begins above at the lower part of the fourth cervical segment and, increasing rapidly, attains its greatest development in the neck in the fifth and sixth segments. It suffers a marked reduction at the level of the seventh cervical nerve, which is followed by a sudden increase in the next segment in which the column presents an additional collection of nerve-cells known as the *accessory dorso-lateral* or *post-postero-lateral group*. Below the level of the second thoracic nerve the dorso-lateral cell-column is unrepresented as far as the second sacral segment where it reappears, somewhat abruptly, and attains its maximum size in the fourth and fifth lumbar segments. The column then diminishes and ceases at the lower part of the third sacral segment. Within the sacral cord, between the levels of the first and third nerve inclusive, the dorso-lateral cell-group is augmented by an *accessory group*. From the third lumbar to the sacral nerve-levels, an additional compact collection of nerve-cells occupies a more median position in the anterior horn and constitutes the *central group*.

From the position of the greatest expansions of the lateral cell-columns—within the cervical and lumbo-sacral enlargements—it is evident that they are associated with the large nerves supplying the muscles of the limbs. Further, according to Bruce, in a general way the size of the radicular cells bears a relation to that of the muscles supplied, the smaller dimensions of the cervical cells, as compared with those of the lumbo-sacral region, corresponding with the smaller size of the upper limb in comparison with that of the lower one.

In addition to the nerve-cells assembled within the foregoing more or less well defined groups, some scattered cells are irregularly distributed through the anterior horn and do not strictly belong to any of the groups.

Below the level of the first coccygeal nerve, the cells of the anterior horn become so diminished in number, that they are no longer grouped with regularity, but, reduced in size, lie uncertainly distributed within the gray matter as far as the lower limits of the conus medullaris.

The **nerve-cells of the posterior horn** are neither as large nor as regularly disposed as the anterior horn cells. Only in one locality, along the median border of the base of the posterior horn, are they collected into a distinct tract, the column of Clarke; otherwise they are scattered without order throughout the gray matter of the posterior cornu. Since, however, the latter comprises certain areas, the cells of the posterior horn may be divided into (1) the *cells of Clarke's column*, (2) the *cells of the substantia gelatinosa Rolandi*, and (3) the *inner cells of the caput cornu.*

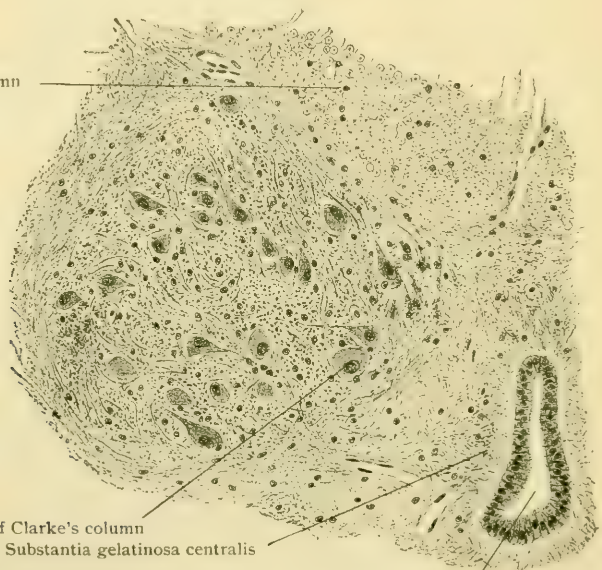
The **cells of Clarke's column** form a very conspicuous collection which extends from the level of the seventh cervical nerve to that of the second lumbar nerve and is best developed in the lower thoracic region of the cord. Although confined chiefly to the dorsal portion of the cord, and hence sometimes designated as the "dorsal nucleus," Clarke's column is represented to a slight degree in the sacral and upper cervical regions (*sacral* and *cervical nuclei* of Stilling). In cross-sections the cell-column appears as a group of multipolar cells that occupy the mesial border of the base of the posterior horn and, where the column is best developed (opposite the origin of the twelfth thoracic nerve), correspond to an elevation on the surface of the gray matter. The cells usually are about .050 mm. in diameter, polygonal in outline and possess a relatively large number of richly branched dendrites that radiate chiefly within the limits of the group (Cajal). The axones commonly spring from the anterior or lateral margin of the cells and course ventrally for a considerable distance before bending outward toward the lateral column of white matter within which, as constituent fibres of the direct cerebellar tract (page 1044), they turn brainward.

[1] Topographical Atlas of the Spinal Cord, 1901.

The **nerve-cells of the substantia gelatinosa Rolandi**, also known as *Gierke's cells*, include innumerable small stellate, less frequently fusiform or pear-shaped elements that measure only from .006–.020 mm., although exceptionally of larger size. Their numerous short dendrites are irregularly disposed and branched. The axones, which always arise from the dorsal pole of the cell, are continued partly to the white matter of the posterior column, within which they divide into ascending and descending limbs, and partly to the gray matter itself, within which they run as longitudinal fibres. Under the name of the **marginal cells** are described the much larger (.035–.055 mm.) nerve-cells which occupy the border of the substantia gelatinosa. They are spindle-shaped or pyramidal in form, their long axes lying parallel or the apices directed towards the Rolandic substance respectively, and constitute a one-celled layer enclosing the substantia gelatinosa, into which many of their tangentially coursing dendrites penetrate. Their axones pass through the substantia gelatinosa and probably continue for the most part within the lateral column, although some enter the posterior column (Cajal, Kölliker).

The **inner cells** of the posterior horn are intermingled with numerous nervous elements of small size irregularly distributed within the head of the dorsal cornu. The inner cells proper are triangular or spindle-shaped in form and, on an average, measure about .050 mm.; they are, therefore, larger than the ordinary cells of the Rolandic substance. The dendrites arise

FIG. 889.



Part of cross-section of cord, showing cells of Clarke's column in base of posterior horn. × 110.

from the angles or ends of the cells and diverge in all directions. The axones pass, either directly or in curves, mostly into the lateral column of the same side; some, however, have been followed into the posterior or anterior columns of the same side (Kölliker), and, rarely, into the opposite anterior column (Cajal). Exceptionally type II cells—those in which the axone is not prolonged as the axis-cylinder of a nerve-fibre, but soon breaks up into an elaborate end-arborization confined to the gray matter—are found within the gray matter of the posterior horn. Their number is, however, much less than often assumed (Ziehen).

The nervous character of most of the cells seen within the substantia gelatinosa Rolandi has been established only since the introduction of the Golgi methods of silver-impregnation. Previously, these elements were regarded as glia cells, an exceptionally large amount of neuroglia in general being attributed to the Rolandic substance. It is now admitted that instead of such being the case, this region of the gray matter is relatively poor in neurogliar elements and numerically rich in nerve-cells.

The **nerve-cells of the pars intermedia** of the gray matter, which connects the dorsal and ventral horns and lies opposite the gray commissure, may be broadly divided into two classes, the *lateral* and the *middle cells*, that occupy respectively the outer border and the more central area of this part of the gray matter of the cord.

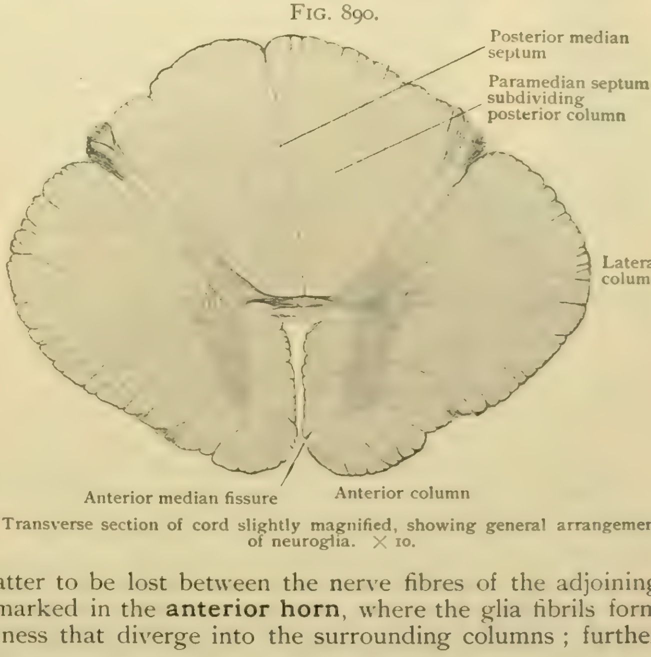
Those of the first class, or **intermedio-lateral cells**, are associated with the formatio reticularis and its condensation, the lateral horn, and hence are often spoken of as the *group* or *column of the lateral horn*. These cells form a slender tract of small closely packed elements that is represented through almost the entire length of the cord, although best marked in the upper third of the thoracic region and partially interrupted in the cervical and lumbo-sacral segments. Where the formatio reticularis is condensed with a distinct lateral horn, as in the thoracic region, the cells occupy the projection, but elsewhere lie within the base of the gray network. As a continuous cell-column the tract extends from the lower part of the eighth cervical segment to the upper part of the third lumbar, being most conspicuous at the level of the third and fourth thoracic nerves (Bruce). Practically suppressed in the cervical region between the eighth and third segments, above the latter the column reappears along with the formatio reticularis. Below, it is again seen within the third and fourth sacral segments. The nerve-cells are multipolar or fusiform in outline, from .015–.045 mm. in their longest diameter, contain little pigment, and are provided with a variable number of dendrites, of which two are usually larger than the others. These arise from opposite poles of the cell and send branches, for the most part, into the adjacent white matter. The axones pass directly into the lateral columns and become ascending or descending fibres ; a few axones, however, enter the anterior column of the same side (Ziehen).

The cells of the second class, or **intermediate cells**, are irregularly disposed and only in the upper part of the cord present a fairly distinct middle group (Waldeyer). They are polygonal or fusiform in outline, small in size (seldom exceeding .025 mm.) and provided with irregular dendrites. The axones are continued chiefly within the lateral column of the same side, although some pass to the anterior column and a few probably cross to the opposite side.

A small number of isolated nerve-cells are usually to be found within the white matter, outside but in the neighborhood of the gray core. These, the **outlying cells** of Sherrington,[1] by whom they have been studied, occur most frequently in the vicinity of the more superficially placed cell-columns. Within the anterior columns they lie in the paths of the fibres proceeding to the anterior white commissure ; in the lateral columns they are in proximity to the intermedio-lateral group of the lateral horn and formatio reticularis and to the cells of the substantia Rolandi ; and in the posterior columns, where they are relatively numerous, they are associated with the fibre-tracts leading to the column of Clarke. The outlying cells are regarded as elements displaced from their usual position during the course of the differentiation and growth of the white and gray matter. Similar displacement sometimes affects the cells of the spinal ganglia, which then may be encountered within the cord.

The Neuroglia of the Gray Matter.—As in other parts of the cord, so in the gray matter the neuroglia is everywhere present as the supporting framework of the nervous elements, the cells and fibres. The general structure of neuroglia having been described (page 1004), it only remains to note here the special features of its arrangement within the gray matter. In general, the felt-work of the neurogliar fibrils is more compact than that permeating the white matter, being somewhat denser at the periphery than in the deeper parts of the gray matter. There is, however, no hard boundary between the supporting tissue of the two, since numerous glia fibrils extend outward from the frame-work of the gray matter to be lost between the nerve fibres of the adjoining columns. This feature is marked in the **anterior horn**, where the glia fibrils form septa of considerable thickness that diverge into the surrounding columns ; further

FIG. 890.



Transverse section of cord slightly magnified, showing general arrangement of neuroglia. × 10.

[1] Proceedings Royal Society, vol. 30, 1890.

the conspicuous processes of the formatio reticularis and the projecting lateral horn consist largely of neuroglia. The larger nerve-cells and their robust processes are ensheathed by interlacements of neuroglia fibrillæ.

In the several parts of the **posterior horn** the amount of neuroglia varies. Thus, the apex consists almost exclusively of glia tissue, while within the **Rolandic substance** the number of glia fibres and cells is unusually small. Within the caput and remaining parts of the posterior horn the neurogliar elements are similar in quantity and disposition to those in the anterior horn.

The **ependyma cells** lining the central canal of the cord are the direct descendents of the radially arranged embryonal supporting elements (page 1004); they may, therefore, be regarded as specialized neuroglia cells. Although most advantageously studied in the fœtus and the child, in favorable preparations from adult cords they are seen as a single row of pyramidal cells, from .030–.050 mm. long and from one-fourth to one-third as broad, whose bases are directed towards the lumen of the canal and beset with cilia. Their pointed distal ends, or apices, are prolonged into a long delicate *ependymal fibre*, that in the adult is soon lost in the surrounding neuroglia, but in the fœtus extends through the entire thickness of the cord. The ependyma cells are not all of equal size, those occupying the ventral mid-line, especially in the cervical region, being about twice as long as those on the opposite wall of the canal. The ependymal fibres proceeding from these cells are of special length and thickness, the ventral ones converging to form a wedge-shaped mass that in the young subject continues as far forward as the bottom of the anterior median fissure. The dorsal ependymal fibres are prolonged through the gray commissure into the posterior median septum, some diverging into the columns of Goll.

Substantia gelatinosa centralis is the name given to a zone of peculiar translucency that immediately surrounds the central canal. This annular area consists of modified neuroglia in which radial ependymal fibers are interwoven with circularly disposed neurogliar fibrillæ, the whole giving rise to a compact stratum, interspersed with an unusual number of glia cells, upon which arrangement, in conjunction with the absence of nerve-fibres, the characteristic appearance of the gelatinous substance depends. In addition to the branched glia elements, a number of radially directed spindle cells are present in this zone; they send delicate processes between the ependyma cells, of which they are probably outwardly displaced members. In marked contrast with the Rolandic substance, which caps the posterior horn, the substantia gelatinosa centralis contains only a few small nervous elements, in recognition of which the term, *substantia gliosa centralis*, has been proposed by Ziehen.

FIG. 891.

Central canal and surrounding substantia gelatinosa centralis, from child's cord; canal is lined with ependyma cells, outside of which lies neuroglia with glia cells. × 135.

The Nerve-Fibres of the Gray Matter.—Within all portions of the gray core a considerable part of the intricate ground-work in which the nerve-cells lie embedded is contributed by the processes of neurones situated at the same, different or even remote levels. These processes, which constitute the nerve-fibres, medullated and nonmedullated, that are seen traversing the gray matter in all directions, include: (1) the collaterals and the terminal branches of the dorsal root-fibres that enter the gray matter; (2) nerve-fibres of the descending tracts that terminate in relation with the ventral (motor) horn cells; (3) the axones and collaterals given off by the numerous posterior horn cells, that traverse the gray matter to and from the respective columns into which they pass. The dendritic processes, as well as the axones of the type II cells, also contribute to the sum of nervous fibrillæ encountered within the gray matter of the cord.

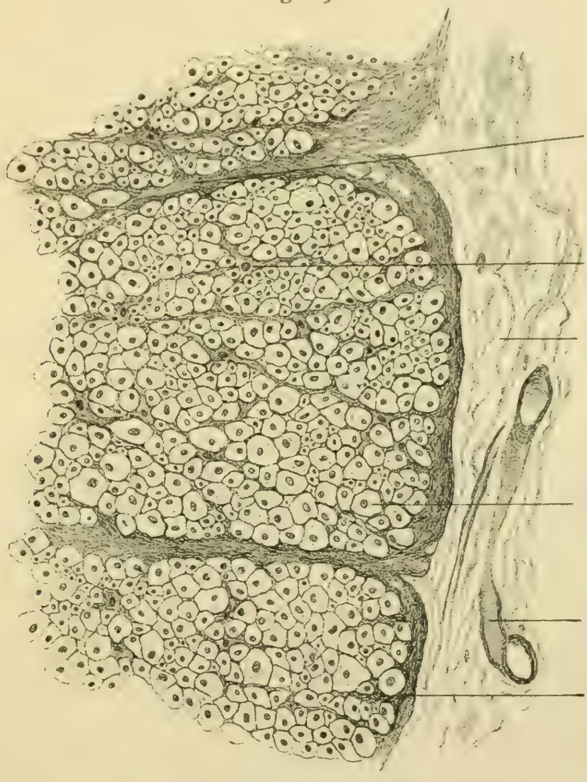
WHITE MATTER OF THE SPINAL CORD.

The predominating components of the white substance being the longitudinal nerve-fibres which pass for a longer or shorter distance up and down in the columns of the cord, in cross-sections the outer field, between the gray core and the periphery

of the cord, appears to be composed of innumerable, closely set, small cells, held together by delicate supporting tissue. These apparent cells are the medullated nerve-fibres cut transversely, in which the sectioned axis-cylinders show as deeply stained dots, that commonly lie somewhat eccentrically and are surrounded by delicate irregularly annular striations representing the framework of the medullary coat. The nerve-fibres of the cerebro-spinal axis are without neurilemma, the lack of this sheath being compensated by a slight condensation of the neuroglia around the fibres. Seen in transverse sections this investment appears as the ring that gives a definite outline to the fibre.

The individual nerve-fibres vary greatly in size, even within the same tract large and small fibres often lying side by side. The smallest may be less than .005 mm. and the largest over .025 mm. In a general way, the diameter of the fibre bears a direct relation to its length, those

Fig. 892.



Peripheral part of transverse section of spinal cord, showing nerve-fibres subdivided into groups by ingrowth of subpial layer of neuroglia. × 230.

having an extended course being larger than shorter ones ; it follows that the fibres occupying the peripheral parts of the white matter, particularly in the lateral columns, are more frequently of large diameter than those near the gray matter.

The immediate surface of the white substance beneath the pia mater is formed by a condensed tract of neuroglia, the **subpial layer**, from .020–.040 mm. in thickness, that is devoid of nervous elements and forms the definite outer boundary of the cord. This zone consists of a dense interlacement of circular, longitudinal and radial neuroglia fibrils among which numerous glia cells are embedded. From the deeper surface of this ensheathing layer numerous bundles of fibrillæ penetrate between the subjacent nerve-fibres to become lost in the general supporting ground-work. At certain places the bundles are replaced by robust septa by which the nerve-fibres are imperfectly divided into groups or tracts, as conspicuously seen in the posterior column where the paramedian septum effects an imperfect subdivision into the tract of Goll and of Burdach. The blood-vessels that enter the nervous substance from the pia, accompanied by connective tissue, are surrounded by tubular sheaths of neuroglia, and the same is

true of the bundles of root-fibres of the spinal nerves. But apart from the connective tissue that enters with the blood-vessels, the amount of mesoblastic tissue concerned in the supporting framework of the cord is inconsiderable, according to some histologists, indeed, being practically nothing.

Fibre-Tracts of the White Matter.—Although microscopical examination of ordinary sections of the cord affords slight indication of a subdivision of the columns of white matter into areas corresponding with definite fibre-tracts, yet the combined evidence of anatomical, pathological, embryological and experimental investigation establishes the existence of a number of such paths of conduction. With few exceptions, they are, however, without sharp boundaries and illy defined, adjoining tracts often overlapping, and depend for their presence upon the fact that nerve-fibres having the same function and destination proceed in company from the same group of nerve-cells (nucleus) along a similar course. In addition to being provided with paths of conduction necessary for the performance of its function as a centre for independent (reflex) impulses in response to external stimuli, the cord contains tracts that connect it with the brain, as well as those that bring the various levels of the cord itself into association. The white matter, therefore, contains three classes of fibres: (1) those entering the cord from the periphery and other parts of the body; (2) those entering it from the brain; and (3) those arising from the nerve-cells situated within the cord itself. The first two constitute the *exogenous*, the last the *endogenous tracts*. It is evident that some of these fibres constitute pathways for the transmission of impulses from lower to higher levels and hence form *ascending tracts*, while others, which conduct impulses in the opposite direction, form *descending tracts*.

Since it is impossible to distinguish between these fibres by mere inspection of sections of the adult normal cord, and, moreover, extremely difficult and practically impossible to follow in such preparations the longer fibres throughout their course, advantage is taken of other means by which differentiation of individual tracts is feasible. Such means include chiefly the experimental and embryological methods.

The **experimental method** depends upon the law discovered by Waller, more than half a century ago, that when the continuity of a nerve-fibre is destroyed, either by a pathological lesion or by the experimenter's knife, the portion of the nerve-fibre (the axone of a neurone) beyond the break, and therefore isolated from the presiding nerve-cell, undergoes secondary degeneration, while the portion remaining connected with the cell usually undergoes little or no change. It should be pointed out, however, that occasionally the connected portion of the fibre, and even the nerve-cell itself, undoubtedly exhibits changes known as retrograde degeneration, which, dependent upon the location of the lesion, may at times prove a source of error in deducing conclusions. If a lateral section of one-half of the cord of a living animal be made, and, after the expiration of from three to four weeks, transverse sections be cut and appropriately prepared (by the methods of Marschi or of Weigert), certain groups of nerve-fibres will present degenerative changes. It will be seen, however, that the degenerated tracts in sections taken from above the lesion are not the same as those in sections from below the division, showing that certain fibres have been involved in opposite directions, those arising from nerve-cells lying below the lesion being affected with ascending degeneration, and those from cells situated above with descending degeneration. In this manner, by careful study of consecutive sections, much valuable information has been gained as to the origin, course, termination and function of many fibre-tracts within the central nervous system.

The **embryological method**, also productive of important advances in our knowledge of the nervous pathways, is based on the fact, first demonstrated by Meckel, that the nerve-fibres of the central nervous system do not all acquire their medullary sheath at the same time. Taking advantage of such variation, as suggested by Meynert and later extensively carried out by Flechsig and others, upon staining sections of embryonal tissue with reagents that color especially the medullary substance, it is possible to differentiate and follow certain fibre-tracts in the fœtal cord with great clearness, since only those tracts are stained in which the myelin is already formed. It is of interest to note that, in a general way, the order in which the different strands of the cord acquire their medullary coat accords with the sequence in which nervous function is assumed by the fœtus and child. Thus, the paths required for spinal reflexes (the posterior and anterior root-fibres) are first to become medullated (fourth and fifth fœtal months); those bringing into association the different segments of the cord next (from the fifth to the seventh month) acquire myelin; those connecting the cord with the cerebellum follow somewhat later, while those establishing relations with the cerebral cortex are last and do not begin to medullate until shortly before birth.

Based on the collective evidence contributed by these methods—anatomical, physiological, and developmental—it is possible to locate and trace with fair accuracy a number of fibre-tracts in the cerebro-spinal axis. Since they are undergoing continual augmentation or decrease, their actual area and position are subject to variation, so that the detailed relations in one region of the cord differ from those at other levels. The accompanying schematic figure, therefore, must be regarded as showing only the general relations of the most important paths of the cord, and not as accurately representing the actual form and size of the fibre-tracts. It must also be appreciated that the definite limits of these tracts in such diagrammatic

FIG. 893.

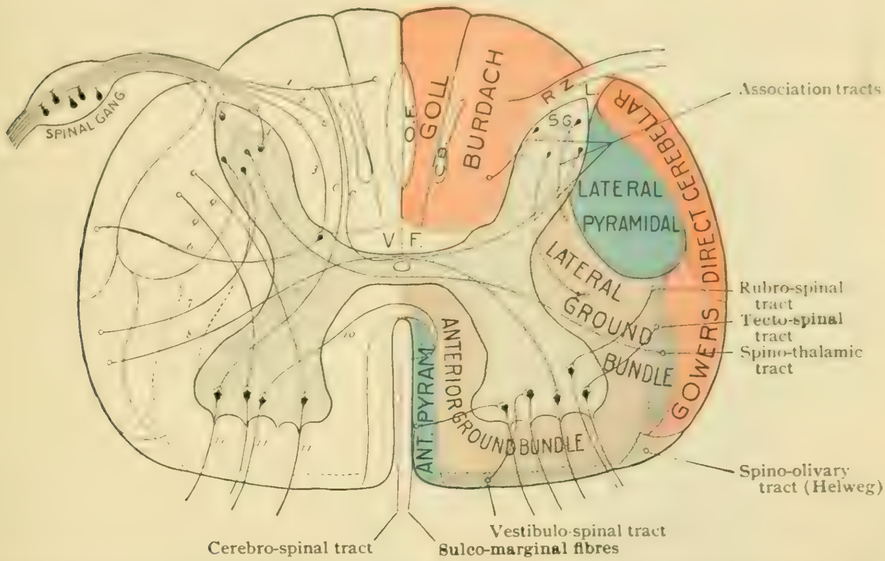


Diagram of spinal cord, showing position of chief tracts and relations of their component fibres to nerve-cells; 1-5, posterior root-fibres entering root-zone (R.Z.) and Lissauer's tract (L.), open circles (o) indicate that fibres pass up and down; *c*, *c*, collaterals from long ascending tracts (1, 2) to anterior root-cells; 3, fibres ending around cells of Clarke's column; 6, fibres forming direct cerebellar tract; 7, 8, fibres forming Gowers' tract; 9, 10, fibres from lateral and direct pyramidal tracts; 11, 11, anterior root-fibres; V.F., ventral field; O.F., oval field; C.B., comma bundle.

representations seldom exist in reality, since the fibres of the adjacent paths in most cases overlap, or, indeed, extensively intermingle, so that the fields seen in cross-sections may be shared by strands belonging to different fibre-systems.

The Fibre-Tracts of the Posterior Column.—The subdivision of the posterior column of white matter by the paramedian septum into two general parts has been noted (page 1028). Of these the inner one is the **postero-median fasciculus**, or **tract of Goll** (fasciculus gracilis), and the outer one is the **postero-lateral fasciculus** or **tract of Burdach** (fasciculus cuneatus). These tracts are so intimately associated with the fibres entering by the posterior roots of the spinal nerves, that the general relations and behavior of these fibres must be considered in order to understand the composition of the posterior columns, as well as that of certain secondary paths.

All sensory impulses that enter the spinal cord do so by way of the posterior root-fibres. The latter are the centrally directed processes (axones) of the neurones whose cell-bodies lie within the spinal ganglia situated on the dorsal roots of the spinal nerves. They convey to the cord the various impulses collected by the peripherally directed processes (the sensory nerves) from the integument, mucous membranes, muscles, tendons and joints from all parts of the body, with the exception of those served by the cranial nerves. The impulses thus conducted are transformed into the impressions of touch, muscle-sense, heat, cold and pain. The last being probably the result of excessive stimulation that by its intensity causes discomfort in various degrees, the existence of special paths for the conduction of painful impressions is unlikely. It is evident that the larger part of the

sensory neurones lies outside the spinal cord ; it is, however, with the intramedullary portion of these neurones, as constituents of paths within the cord, that we are here concerned.

On entering the spinal cord along the postero-lateral groove, the **dorsal root-fibres** for the most part penetrate the tract of Burdach, close to the inner side of the posterior horn. Some of the more external root-fibres, however, do not enter Burdach's tract, but form a small adjoining field, the **tract of Lissauer,** that lies immediately dorsal to the apex of the posterior horn. Soon after gaining the posterior column, with few exceptions, each dorsal root-fibre undergoes a ≻ or ⊢ like division into an ascending and a descending limb, which assume a longitudinal course and pass upward and downward in the cord for a variable distance, the descending limb being usually the shorter. During their course from both, but particularly from the descending limb and from the proximal part of the ascending fibre, collateral branches are given off which bend sharply inward and pass horizontally into the gray matter to end chiefly in relation with the neurones of the posterior horn, from which cells secondary paths arise. Not only the collaterals, but also the main stem-fibres of the descending and shorter ascending limbs end in the manner just described. In addition to the short collaterals destined for the cells of the dorsal horn, others, the **ventral reflex collaterals,** pursue a sigmoid course, traversing the substantia gelatinosa Rolandi and the remaining parts of the posterior horn and the intermediate gray matter, to end in arborizations around the radicular cells of the anterior horn, and thus complete important reflex arcs, by which impulses transmitted through the dorsal roots directly impress the motor neurones. The latter are usually of the same side, but some collaterals cross by way of the anterior commissure to terminate in relation with the anterior horn cells of the opposite side. It is probable that a considerable number of such anterior horn reflex collaterals are given off from the fibres that ascend in the long tracts of the posterior column to the medulla oblongata.

FIG. 894.

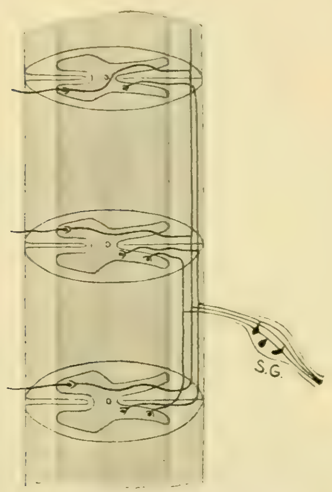


Diagram showing division of posterior root-fibres into ascending and descending branches ; long fibre sends collaterals to anterior root cells ; other fibres end at different levels around cells in gray matter of posterior horn ; S. G., spinal ganglion.

With possibly the exception of certain fibres which pass directly to the cerebellum (Hoche), all the sensory root-fibres (axones of neurones of the I order) end around the neurones situated either within the gray matter of the spinal cord or within the nuclei of the medulla ; thence the impressions are conveyed by the axones of these neurones of the II order to higher centers, to be taken up, in turn, by neurones of the III or even higher order, in the sequence of the chain required to complete the path for the conduction and distribution of the impulse.

The most important groups of the collaterals and stem-fibres of the posterior roots are:

1. The long ascending tracts passing chiefly to the nuclei of the medulla.
2. The fibres passing to the cells of the column of Clarke.
3. The collaterals passing to the anterior horn cells.
4. The fibres entering the posterior horn from the tract of Burdach and of Lissauer to end about the neurones of the II order situated within the gray matter of the posterior horn and the intermediate gray matter.

The **direct ascending posterior tract** includes the dorsal root-fibres that pass uninterruptedly upward within the posterior column as far as the nuclei of the medulla. On entering the cord they lie at first within the tract of Burdach, but in their ascent are gradually displaced medianly and dorsally by the continued addition of other root-fibres from the succeeding higher nerves. In consequence, in cross

sections of the cord in the cervical region the long fibres entering by the lower nerve-roots occupy the inner part of Goll's column. In the lumbar cord, they are excluded from the median septum by a narrow hemielliptical area, which with that of the opposite side forms the **oval field** of Flechsig. The fibres entering by the lower thoracic nerves lie more laterally, while those entering by the upper thoracic and cervical nerves appropriate the adjoining part of Burdach's tract, the lateral area of which, next the posterior horn, is occupied chiefly by the posterior root-fibres.

It must be understood that while in a general way the fibres of the long ascending tracts have the disposition just indicated, they are so intertwined and mingled with the strands passing to and from the gray matter that the definite outlines of their conventional area, as represented in diagrams, are wanting. Collectively the fibres composing this tract are of medium or small size, but acquire their medullary coat very early, myelination beginning about the fourth fœtal month, although not completed until the ninth (Bechterew).

FIG. 895.

Section of spinal cord at level of second cervical segment; formatio reticularis fills bay between posterior and anterior cornua; substantia gelatinosa caps apex of posterior cornu. Drawn from Weigert-Pal preparation made by Professor Spiller. × 6.

The termination of the long ascending fibres is chiefly in relation with the neurones within the lower part of the medulla—the fibres of Goll's tract ending about the cells of the nucleus gracilis and those of Burdach's tract about the cells of the nucleus cuneatus. From these stations paths of the II order convey the impulses to the cerebellum, by way of the inferior cerebellar peduncle, and to the higher sensory centres by way of the mesial fillet, as later described (page 1115). Whether certain of the component fibres of these ascending tracts are directly continued to the cerebellum, and perhaps to the mesial fillet, without undergoing interruption in the nuclei of the medulla is still uncertain, although supported by the statements of Hoche, Kölliker, Sölder and others.

The **root-fibres passing to Clarke's column** occupy the middle and median part of Burdach's tract, mingled with those of the long ascending paths. After coursing longitudinally, usually for some distance, within the posterior column, they bend outward, and, sweeping in graceful curves, enter the gray matter to end about Clarke's cells. It is noteworthy that the level at which they end is often considerably higher than that at which the root-fibres enter the cord, an arrangement which explains the fact that lesions of the lowermost of these strands may be followed as ascending degenerations into the thoracic region (Mayer). On entering the gray matter the terminal arborization of a single root-fibre usually ends in relation with several neurones of Clarke's column (Lenhossék). The important sensory path of the II order, known as the direct cerebellar tract (page 1044), arises as the axones of these neurones.

The **anterior reflex fibres** to the ventral horn are all collaterals, not continuations of the stem-fibres, far the greater part of which come from the fibres of the long ascending posterior tract. These collaterals penetrate the gray matter principally at the median border of the head of the posterior horn, behind Clarke's column, but partly also through the substantia Rolandi, and thence pass ventrally or ventro-laterally, with a slightly curved or sigmoid course, towards the anterior horn. As they enter the latter, the collaterals diverge more and more and are distributed to the various groups of the anterior horn cells, chiefly in relation with the lateral groups of radicular cells from which the ventral root-fibres arise; they thus establish direct reflex paths by which sensory impulses conveyed by the posterior root-fibres impress the motor neurones, while, at the same time, these impulses are transmitted

to higher levels by the ascending stem-fibres. Although the anterior reflex collaterals are, for the most part, in relation with the cells of the same side, it is probable that some cross by way of the posterior commissure, and possibly also by the anterior bridge, to the opposite ventral horn cells. It is doubtful, on the other hand, whether either stem-fibres or collaterals of the posterior roots pass directly to the anterior column either of the same or opposite sides (Ziehen).

The **root-fibres passing to the posterior horn** include those which penetrate the substantia Rolandi, either as collaterals or stem-fibres of Burdach's or of Lissauer's tracts, to end about the neurones within the Rolandic substance or within the head of the posterior horn. Their longitudinal course within Burdach's tract is ordinarily short; they then bend horizontally and enter the gray matter of the posterior horn, within which they soon terminate in end-arborizations around the neurones of the II order. Some fibres, however, do not undergo T-division until after entering the posterior horn, where, within the Rolandic substance or caput cornu, they then bifurcate, in some cases the ascending limbs pursuing a vertical course within the gray matter, particularly of the caput cornu, for some distance before ending about the head-cells of the posterior horn.

FIG. 896.

Section of spinal cord at level of sixth cervical segment; anterior cornua are very broad; obliquely cut bundles of posterior root-fibres lie in postero-lateral sulcus. Preparation by Professor Spiller. × 6.

The **tract of Lissauer**, or **marginal zone**, situated immediately behind the apex of the dorsal horn, receives the lateral group of the posterior root-fibres. These are all of unusually small size and, after a short longitudinal course in which the descending limbs predominate, they turn horizontally and, both as collaterals and stem-fibres, penetrate the substantia Rolandi, about whose cells and those of the caput cornu they end.

From the foregoing description, it is evident that the dorsal root-fibres destined for the posterior horn terminate in relation with neurones of the II order represented chiefly by the cells of the substantia gelatinosa Rolandi, including the marginal cells, and the inner cells of the caput cornu.

The secondary or **endogenous tracts of the posterior column** arise as axones from the neurones of the II order (the marginal cells, the cells of the substantia Rolandi and the head-cells) situated within the posterior horn and include ascending and descending paths.

The **ascending secondary tract** is composed of the axones derived from the posterior horn cells of the same and, by way of the posterior commissure, opposite side, which pass into the posterior column. In a general way, they occupy the **ventral field**, although sharing it with scattered strands of root-fibres and of descending endogenous fibres. The destination of the fibres of this ventral tract is uncertain, some fibres pursuing a short and others a longer course within the posterior column before entering the gray matter at higher levels to end in relation with the posterior horn-cells, or, perhaps, in some cases, with the neurones within the nuclei of the medulla (Rothmann).

The **descending secondary tracts**, as shown by degenerations following lesions involving the posterior column, occupy varying but fairly well differentiated areas. In the cervical and upper thoracic cord the descending limbs of the long posterior fibres are collected into the **comma bundle** of Schultze, which extends along the median margin of Burdach's tract. In the lower thoracic and lumbar cord is formed an elongated half-ellipse along the posterior median septum which, with the corresponding bundle of the opposite side, produces the **oval field** of Flechsig. Still lower, in the sacral cord, fibres lie at the junction of the median septum and the posterior surface of the cord as the medio-dorsal **triangular bundle** of Gombault and Philippe. Additional descending endogenous fibres are scattered in the ventral field. It is

likely that these areas represent the principal aggregations of the downward coursing limbs of the axones, derived from the posterior horn cells of the same and opposite sides. In the cervical region the descending limbs of the posterior root fibres appear as the comma tract; in the lower thoracic cord these are replaced by, without being directly continuous with, those forming the oval field, and these in turn by the axones of the triangular bundle. No one of these fields is exclusively devoted to the descending limbs of endogenous fibres, since in all the presence of exogenous posterior root-fibres has been demonstrated.

Fig. 897.

Section of spinal cord at level of seventh cervical segment; anterior cornua are less robust; root-zone is seen just behind Lissauer's tract. × 6. Preparation by Professor Spiller.

The Fibre-Tracts of the Lateral Column.—These include: (1) the lateral pyramidal, (2) the direct cerebellar, (3) the ascending antero-lateral, and (4) the lateral ground-bundle.

The **lateral** or **crossed pyramidal tract** (fasciculus cerebrospinalis lateralis) forms the chief path by which motor impulses originating in the cerebral cortex are conveyed to the spinal cord. It stands in close relation with the direct pyramidal tract of the anterior column. Both are continuations of the conspicuous pyramidal paths of the medulla oblongata and may be followed upward through the ventral part of the medulla, the pons and the cerebral peduncles into the white matter of the cerebral hemispheres and on to the cortical gray matter where, in the motor areas bordering chiefly the Rolandic fissure, lie the nerve-cells from which the pyramidal fibres arise. These fibres, therefore, are the axones of cortical motor neurones and extend without interruption from the superficial gray matter of the cerebral hemispheres to various levels in the cord, constituting long descending (corticifugal) motor tracts. On reaching the lower part of the medulla, from 80–90 per cent. of the component fibres of each pyramid cross to the opposite side by way of the decussation of the pyramids (page 1065) and, entering the cord, descend as the lateral pyramidal tract; the remaining fibres (on an average, about 15 per cent.) pass downward into the ventral column of the cord as the direct pyramidal tract.

After decussating, the crossed pyramidal tract passes outward to enter the lateral column of the cord, thereby exchanging its former median and superficial position for a deeper and more lateral one. Since its fibres are continually entering the gray matter to end about the radicular cells from which the anterior root-fibres of the spinal nerves arise, the tract progressively loses in size as it descends, until, at about the level of the fourth sacral nerve, it ceases to exist as a distinct strand, although continued by small scattered bundles of fibres as far as the origin of the coccygeal nerve. This diminution is not regular, since in the sacral and lumbar enlargements the loss is more marked than elsewhere, on account of the relations of the tract-fibres to the large motor limb-nerves.

The relations, as well as size, of the lateral pyramidal tract vary at different levels. As seen in cross-sections of the upper thoracic region of the cord, the tract occupies an area of considerable size, that mesially lies against the posterior horn and laterally is in contact with the direct cerebellar tract, by which it is excluded from the periphery. In front, where its limits are less definite, the tract extends ventrally for a variable distance into the lateral column, but seldom overreaches the plane of the gray commissure. With the diminution and disappearance of the direct cerebellar tract within the lower portions of the cord, the pyramidal field approaches and finally reaches the surface, which relation it retains as it grows smaller, the

reduction affecting the more deeply placed fibres. In consequence of these variations, the form of the pyramidal tract in cross-section changes from wedge-shape to triangular, with the base lying at the periphery and the apex directed inward. During their descent the fibres of the pyramidal tract give off at different levels collaterals, which bend horizontally inward and forward, enter the gray matter, and end in relation with the anterior horn cells. A similar course is followed by the parent fibres on reaching the segment for which they are destined, the terminal part of the individual fibres sweeping in short curves through the intervening ground-bundle of the lateral column to gain the radicular cells around which they end. By means of its collaterals, each pyramidal fibre establishes relation with several cord-segments. The fibres of this tract are relatively tardy in acquiring their medullary coat, which process does not begin until the last month of fœtal life and is not completed until after the second year.

FIG. 898.

Section of spinal cord at level of sixth thoracic segment; slender posterior cornua covered with substantia gelatinosa; postero-lateral angle marks greatest width of anterior cornu. × 6. Preparation by Professor Spiller.

The **direct cerebellar tract** (**tractus spino-cerebellaris dorsalis**), is an ascending path of the second order that establishes communication between the reception sensory cord-nucleus formed by Clarke's cells and the cerebellum. In cross-sections of the thoracic region, the tract forms a superficial flattened comet-shaped field that occupies the dorsal half of the lateral column, extending from the apex of the posterior horn forward along the periphery of the cord, to the outer side of the lateral pyramidal tract, to about the anterior plane of the gray commissure. Its ventral end, particularly in the lower cervical region, is broadest and projects somewhat into the lateral column in advance of the lateral pyramidal field. Although as a compact strand the direct cerebellar tract begins at the tenth thoracic segment, it is represented by isolated fibres in the lumbo-sacral region. The fibres collectively are large and become medullated about the sixth fœtal month (Bechterew). In a general way the fibres having the longest course occupy the dorsal part of the tract and those having the shortest the ventral (Flatau).

Arising as the axones of the cells of Clarke's column, the components of the tract pass in curves almost horizontally outward through the gray matter and lateral column to the peripheral field, on gaining which they bend sharply brainward and ascend without interruption to the medulla. Their further course includes the passage through the dorso-lateral field of the medulla as far as the inferior cerebellar peduncle, by which the fibres reach the cerebellum to end in relation with the superior worm, on, probably, both the same and the opposite sides.

The **tract of Gowers** (**tractus spino-cerebellaris ventralis**) constitutes another pathway of the II order, which connects the cord with the cerebellum and probably also establishes relations with the cerebrum. In cross-sections the tract appears somewhat uncertainly defined owing to the intermingling of its fibres with those of adjoining strands, but in the main it includes a superficial crescentic field that touches the direct cerebellar and lateral pyramidal tracts behind, extends along the margin of the cord for a variable distance, and usually ends in front in the vicinity of the ventral nerve-roots. The inner boundary, separating the tract in question from the lateral ground-bundle, lacks in sharpness and is overlaid by the adjoining strands. Below, the tract appears about the middle of the lumbar region and continues throughout the remainder of the cord. As Gowers' tract ascends, it fails to show the considerable increase in size that might be expected in view of the continual additions that it receives. In explanation of this, the probable mingling of some of its fibres with those of the direct cerebellar tract, rather than their ending in the cord, seems the most plausible (Ziehen).

The exact origin of the constituents of Gowers' tract is still uncertain, but it is very likely that its fibres are chiefly the axones of the neurones (marginal and inner cells) situated within the posterior horn, partly from the same and partly from the

opposite sides, with contributions, possibly, from the cells of the intermediate gray matter. After traversing the cord, the lateral field of the medulla, and the tegmental portion of the pons, the tract ascends the brain stem to the vicinity of the inferior corpora quadrigemina. Here the major part of the fibres turn backward and, by way of the superior cerebellar peduncle and the superior medullary velum, reach the cerebellum to end mostly in the superior worm, partly on the same side and partly crossed (Hoche). Possibly a part of the cerebellar contingent may share the path of the direct cerebellar tract and in this way reach the cerebellum by its inferior peduncle (Ziehen). It is possible that all fibres from Gowers' tract do not pass to the cerebellum, but that some continue upward to terminate in relation with the neurones of the superior corpora quadrigemina and of the optic thalamus. The fibres of the tract acquire the medullary coat about the beginning of the eighth month of fœtal life (Bechterew).

FIG. 899.

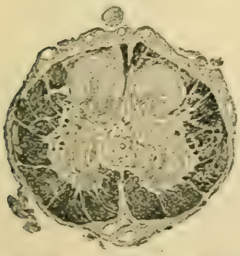
Section of spinal cord at level of lower part of fifth lumbar segment; gray matter relatively large in amount; anterior cornua bulky. Preparation by Professor Spiller. × 6.

The **lateral ground-bundle** (fasciculus lateralis proprius) of Flechsig includes the remainder of the lateral column. Much uncertainty prevails as to its detailed paths, but beyond question the composition of the ground-bundle is very complex and comprises a number of long exogenous paths that descend from the brain, as well as one long ascending and many shorter endogenous strands, both ascending and descending. These *short tracts* occupy chiefly the central parts of the lateral column and, in a general way, lie close to the gray matter, within an area between the anterior and posterior horns, known as the **boundary zone.** They are, however, not limited to this field, as not a few of their fibres lie scattered among the longer exogenous tracts occupying the more lateral portions of the ground-bundle.

One long endogenous path, the **spino-thalamic tract,** is of unusual importance since it establishes a direct sensory link between the cord and higher centres. This tract arises from the cells of the posterior horn of the opposite side, the axones crossing in the anterior commissure to pursue a course brainward within the antero-lateral ground-bundle. Although the fibres of this tract are scattered and not collected into a compact strand, their chief location is just medial to Gowers' tract. Associated with the fibres destined for the optic thalamus are others (*tractus spino-tectalis*) that end in the region of the corpora quadrigemina.

The **short endogenous tracts** include both ascending and descending fibres which arise as the axones chiefly of the marginal and inner cells of the posterior horn, some coming from the opposite side by way of the posterior intracentral commissure. Entering the lateral column the axones undergo T-like division with ascending and descending limbs. The former pass upward for a distance that usually includes only from one to three segments, then bend inward and enter the gray matter to end probably in relation with other posterior horn cells. The downwardly directed limbs form the descending endogenous fibres, which, in addition to occupying the boundary zone are also scattered among the longer tracts of the ground-bundle. After a relatively long course, they enter the gray matter to end probably in relation with the anterior horn cells. They are, therefore, regarded as establishing reflex-paths. Since these endogenous strands link together various levels of the cord, they are often collectively termed **intersegmental association fibres.**

FIG. 900.



Seciton of spinal cord at level of third sacral segment; posterior cornua with substantia gelatinosa are relatively bulky. Preparation by Professor Spiller. × 8.

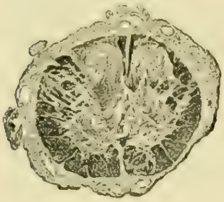
The **exogenous tracts** of the lateral ground-bundle are closely related with those found in the ground-bundle of the anterior column and what may be said of the former largely applies to the latter. Notwithstanding the study that these tracts have received, much uncertainty exists as to their exact origin and termination; it may be stated in a general way, however, that they bring the higher sensory and coördinating centres into relation with the spinal cord and constitute, therefore, descending paths other than the

pyramidal tracts. Among those whose existence within the antero-lateral ground-bundle may be considered as established, are the following:

1. *Rubro-spinal fibres* from the cells of the red nucleus within the cerebral peduncles.
2. *Tecto-spinal fibres* from the cells of the anterior corpora quadrigemina.
3. *Vestibulo-spinal fibres* from the cells of the lateral vestibular (Deiters') nucleus.
4. *Olivo-spinal fibres* from the cells of the inferior olivary nucleus.

Of these strands, those from the red nucleus and corpora quadrigemina (tecto-spinal fibres), descend within the lateral ground-bundle, whilst the vestibulo-spinal fibres are particularly within the anterior ground-bundle. Although the latter includes the greater part of the vestibulo-spinal fibres, which occupy the ventral margin of the ground-bundle, perhaps similar fibres (*tractus vestibulo-spinalis lateralis*) descend within the lateral column mesial to the tract of Gowers. Associated with the spino-thalamic tract are fibres, which probably arise within the thalamus; hence, thalamo-spinal fibres are recognized. For the most part, the exogenous strands are so intermingled and scattered, that they are without definite boundaries. An exception is presented by the olivary fibres, which constitute a fairly distinct triangular bundle, known as **Helweg's tract,** situated at the periphery of the cord and just behind the anterior root-fibres. Concerning the exact relations of these fibres much uncertainty exists, since by some they are regarded as a descending (olivo-spinal) path and by others as an ascending (spino-olivary) one. It is probable that fibres course in both directions. Collectively, these scattered descending paths are of importance, since they bring the ventral horn cells under the coördinating influence of the higher centres.

FIG. 901.



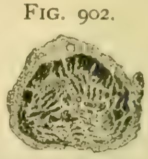
Section of spinal cord at level of fifth sacral segment; anterior cornua small and inconspicuous. Preparation by Professor Spiller. × 8.

The Fibre-Tracts of the Anterior Column.—According to the simplest classification the anterior column includes two subdivisions: (1) the anterior pyramidal tract and (2) the anterior ground-bundle.

The **anterior pyramidal tract** (fasciculus cerebrospinalis anterior), also called the *uncrossed* or *direct pyramidal tract*, stands in complemental relation with the lateral pyramidal fasciculus, being composed of the pyramidal fibres that do not undergo decussation in the medulla oblongata. It usually contains about 15 per cent. of the pyramidal fibres, but may include a much larger proportion; on the other hand, it may be entirely suppressed when, as rarely happens, total crossing occurs.

The direct pyramidal tract occupies the inner part of the anterior column, forming a narrow area along the median fissure that extends from the white commissure behind to near the ventral margin of the cord. Ordinarily the tract ends below about the middle of the thoracic cord, but in exceptional cases, when a larger proportion of the pyramidal fibres than usual is included in the tract, it may extend as far as the middle of the lumbar enlargement, with corresponding increase in its cross area. If, on the other hand, the number of uncrossed fibres is unusually small, the tract may reach only as far as the cervical enlargement, with a reduction of its sagittal dimension. Although often spoken of as the "uncrossed" pyramidal tract, this characteristic applies only to the relation of the fibres at the decussation in the medulla, since in their downward journey in the cord the great majority of the fibres traverse the anterior white commissure at appropriate levels to end in arborizations about the ventral root-cells of the anterior horn of the opposite side. It is highly probable, however, that some fibres do not undergo decussation, but terminate about the radicular cells of the same side.

FIG. 902.



Section of spinal cord at level of lower part of coccygeal segment; differentiation of cornua is uncertain. Preparation by Professor Spiller. × 8.

The **anterior ground-bundle** (fasciculus anterior proprius), following the division of Flechsig, includes the remainder of the ventral column. In front, where its lateral limits are uncertain, it is continuous with the ground-bundle of the lateral column, the two together being often with advantage regarded as constituting a single *antero-lateral tract*. What has been said concerning the constitution of the lateral ground-bundle applies in the main to that of the anterior column, since, here as there, the region bordering the gray matter contains chiefly the short endogenous strands, while the more peripheral parts of the ground-bundle are occupied by the long exogenous paths, intermingled, however, with the longer intrinsic fibres.

The **endogenous fibres** arise as the axones, chiefly of the inner cells of the posterior horn, as well as from the cells of the intermediate gray matter (Ziehen), and in great measure cross by way of the anterior white commissure to the opposite anterior column. After undergoing T-division, their upwardly directed limbs constitute the ascending paths and those coursing downward the descending ones. While both sets of fibres for the most part pursue only a short path, that of the descending limbs is usually the longer, the fibres entering the gray matter to end in relation with the anterior horn cells of lower levels. They are, therefore, regarded as secondary reflex paths. The termination of the ascending limbs is uncertain, but probably is within the gray matter of the posterior horn.

The **exogenous tracts** of the anterior ground-bundle, have been mentioned in connection with those of the lateral column. Certain endogenous fibres claim attention, which ascend partly intermingled with the fibres of the vestibulo-spinal tract and partly within the ventral portion of the anterior ground-bundle, although not grouped as a consolidated tract. These fibres belong to the important spino-thalamic system and take origin from the posterior horn-cells of the opposite side of the cord. After crossing by way of the white commissure, instead of cutting through the adjacent anterior horn and ascending amongst the constituents of Gowers' tract, the fibres in question arch ventrally and pass brainward intermingled with the vestibulo-spinal fibres. This part of the path connecting the spinal cord with the thalamus is sometimes noted as the **anterior spino-thalamic tract** and, according to some authorities, is concerned particularly in carrying impulses of pressure and touch. The anterior column also probably contains fibres that descend from the roof nucleus of the cerebellum and from the quadrigeminal bodies. Since most of such fibres occupy a ventro-median position, they have been designated the **sulco-marginal tract.**

In recapitulation the chief fibre-tracts of the spinal cord may be grouped as follows:

I. **Within the Posterior Column**—
- *Ascending Paths:*
  - Direct ascending posterior root-fibres.
  - Ascending endogenous fibres.
- *Descending Paths:*
  - Descending posterior root-fibres (comma tract).
  - Descending endogenous fibres.

II. **Within the Lateral Column**—
- *Ascending Paths:*
  - Direct cerebellar tract.
  - Gowers' tract.
  - Spino-thalamic tract.
  - Spino-tectal tract.
  - Short endogenous fibres.
- *Descending Paths:*
  - Lateral pyramidal tract.
  - Indefinite exogenous tracts (including the rubro-spinal, quadrigemino-spinal and olivo-spinal).
  - Descending endogenous fibres.

III. **Within the Anterior Column**—
- *Ascending Paths:*
  - Ascending endogenous fibres from posterior horn cells.
  - Ascending endogenous fibres from anterior horn cells.
- *Descending Paths:*
  - Direct pyramidal tract.
  - Vestibulo-spinal tract.
  - Sulco-marginal tract

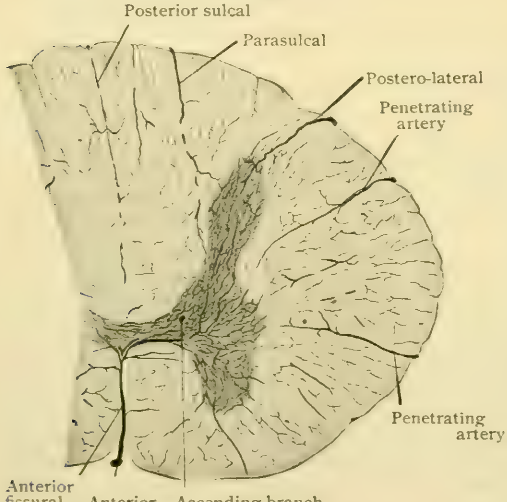
Blood-Vessels of the Spinal Cord.—The *arteries* supplying the cord are from many sources—the vertebral, deep cervical, intercostal, lumbar, ilio-lumbar and lateral sacral of the two sides—since the vascular net-work within the pia accompanies the nervous cylinder throughout its length. Above and within the skull, the vertebral arteries give off the two *anterior* and the two *posterior spinal arteries*, of which the latter retain their independence and descend upon the dorso-lateral surface of the cord, one on each side, in front of the posterior nerve-roots. The two anterior spinal arteries, on the other hand, soon unite (somewhere above the level of the third cervical nerve) into a single trunk, which descends along the ventral surface of the cord, just in front of the anterior median fissure.

As these stems pass downward, they are joined and reinforced by the *segmental spinal branches* given off by the vertebral, intercostal, lumbar and lateral sacral arteries, which enter the spinal canal through the intervertebral foramina and, after piercing the dura and giving off small *radicular branches* to the nerve-roots themselves, divide into ventral and dorsal branches that follow the respective nerve-roots to the cord, where they join with the longitudinal trunks which they thus assist in maintaining. By the junction of horizontal branches arising from these arteries, a series of complete annular anastomoses is formed around the cord, which is still further enclosed by additional vertical stems resulting from the union of upward and downward coursing twigs. In this manner, in addition to the large single anterior spinal trunk (*tractus arteriosus spinalis anterior*) in the mid-line in front and the paired postero-lateral trunk (*tractus arteriosus postero-lateralis spinalis*) just in advance of the dorsal nerve-roots, smaller longitudinal arteries are formed at the side and in the vicinity of the nerve-roots.

From the arterial net-work within the pia, the nervous tissue is supplied by *penetrating twigs* that enter the surface of the cord at various points.

The **gray matter** receives its principal blood-supply from the series of *anterior fissural arteries*, over two hundred in number, which pass from the anterior spinal trunk backward within the median fissure to its bottom and there divide into right and left branches, which traverse the anterior white commissure to gain the gray matter on either side of the central canal. These vessels, the *sulco-marginal arteries*, divide into ascending and descending branches that provide for the entire gray matter with the exception of the most peripheral zone. The latter, together with the **white matter**, receives its supply from the *penetrating branches* that come from the surrounding intrapial trunks and enter the surface of the cord. Unpaired horizontal twigs, the *posterior sulcal arteries*, follow the posterior median septum at different levels for some distance, but before reaching the posterior commissure usually break up into terminal ramifications, some of which pass to the gray matter of the posterior horns. Communications exist between the penetrating twigs of the radicular arteries and the lateral branches of the anterior fissural. After entering the nervous tissue, however, each artery provides the sole supply for some definite part of the cord; they are therefore "end-arteries," a fact which explains the extensive and elaborate system of vessels necessary to maintain the nutrition of the cord.

FIG. 903.



Part of transverse section of injected spinal cord showing vascular supply of white and gray matter. × 10.

The plexiform *veins* within the spinal pia are formed by the union of the small radicles that collect the blood from the intraspinal capillaries and, after an independent course similar to that of the arteries but not accompanying them, emerge at the surface of the cord. From the venous net-work within the pia six main longitudinal trunks are differentiated. These are:—the unpaired *anterior median vein*, in front of the corresponding fissure; the paired *antero-lateral veins*, just behind the ventral nerve-roots—these two sets receiving the tributaries emerging from the median fissure and in the vicinity of the anterior root-fibres; the unpaired *posterior median vein*, behind in the mid-line; and the *paired postero-lateral veins*, just behind the dorsal roots. The blood is conveyed from these intrapial channels chiefly by the *radicular veins*, following the nerve-roots, which communicate with or terminate in the anterior and posterior longitudinal *spinal veins* within the vertebral canal, from which the

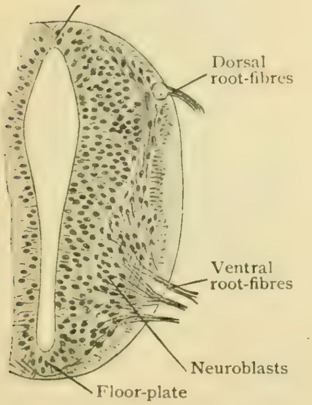
intervertebral efferents carry the blood into the vertebral, intercostal, lumbar and lateral sacral veins. A part of the blood from the intrapial plexus is conducted upward by the anterior and posterior median veins into the venous net-work covering the pons and thence into the lower dural sinuses.

Definite *lymphatic vessels* within the spinal cord are unknown.

Development of the Spinal Cord.—A sketch of the general histogenetic processes leading to the differentiation of the neurones and the neuroglia has been given (page 1009); it remains, therefore, to consider here the changes in the neural tube by which the definite spinal cord is evolved. From the time of its closure, probably about the end of the second week of fœtal life, the neural tube presents three regions:—the relatively thick *lateral walls* and the thin ventral and dorsal intervening bridges, the *floor-* and *roof-plates*, that in front and behind complete the boundaries of the canal in the mid-line. By the fifth week the lateral walls exhibit a distinct differentiation into three zones—the inner *ependymal layer*, the middle *nuclear layer* and the outer *marginal layer*, surrounded by the *external limiting membrane*. In contrast to the other two, the marginal zone is almost devoid of nuclei and, beyond affording support and perhaps assisting in providing a medullary coat, plays a passive rôle in the production of the nervous elements.

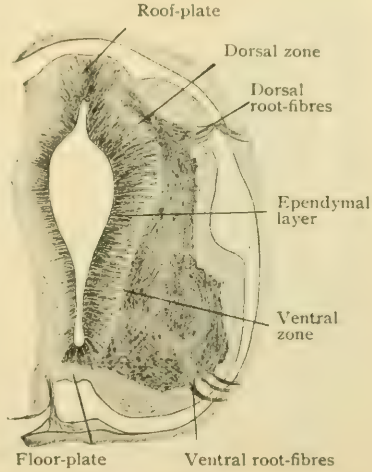
By this time the former general oval contour of the developing cord, as seen in cross-sections, has become modified by the conspicuous thickening of the antero-lateral area of the nuclear layer into a prominent mass on each side, whereby the reticular marginal layer is pushed out-

FIG. 904.



Developing spinal cord of about four weeks. × 100. (*His.*)

FIG. 905.



Developing spinal cord of about five weeks. × 60. (*His.*)

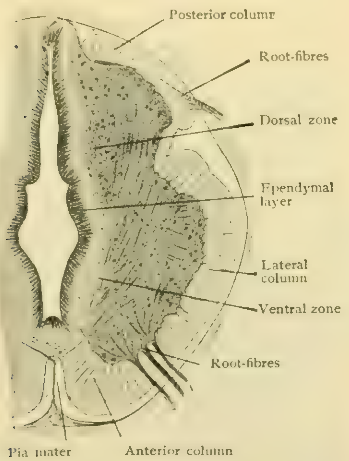
ward with corresponding increase in the width of the entire ventral part of the cord, which is now broadest in front. Within this thickened ventro-lateral part of the nuclear layer, later the anterior horn of gray matter, as early as the fourth week young neurones are seen from which axones grow outward through the marginal zone and pierce the external limiting membrane as the representatives of the anterior root-fibres of the spinal nerves. Postero-laterally the thin nuclear layer is covered by a somewhat projecting thickened area within the marginal layer, known as the *oval bundle*, whose presence is due to the ingrowth of the developing dorsal root-fibres from the sensory neurones of the spinal ganglion, which process begins as early as the end of the fourth week (His).

Associated with these changes, the lumen of the cord becomes heart-shaped in consequence of a conspicuous local increase in its transverse diameter, with corresponding bulging of the lateral wall. In this manner a longitudinal furrow appears by which the side walls of the tube are differentiated into two tracts, the *dorsal* and the *ventral zones* (the alar and basal laminæ of His). This subdivision is of much importance, since in the cord-segment, and also with less certainty in the brain-segment of the neural tube, these tracts are definitely connected with the root-fibres of the spinal nerves, the dorsal zone with the sensory and the ventral zone with the motor roots. In advance of the floor-plate the ventrally protruding halves of the cord include a broad and shallow furrow which marks the position of the anterior median fissure. During the sixth week the form of the tube-lumen becomes further modified by the elongation and narrow-

ing of the dorsal part of the canal in consequence of the approximation of its walls, which in the course of the seventh week is closer and, by the end of the second month is completed by the meeting and fusion of the adjacent inner layers, with obliteration of the intervening cleft and the production of the *posterior median septum* in its place. Since the partition is formed by the union of the inner (ependymal) layers, it is probable that the septum is to be regarded as essentially neurogliar in origin and character. It must be remembered, however, that a certain amount of mesoblastic tissue may be later introduced in company with the blood-vessels which subsequently invade the septum. The remaining and unclosed part of the lumen for a time resembles in outline the conventional spade of the playing card, with the stem directed ventrally; but later gradually diminishes in size and acquires the contour of the definite central canal.

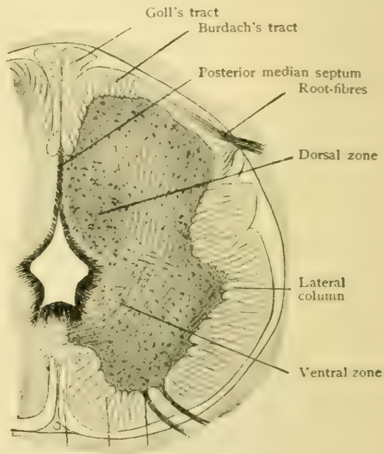
During these alterations in the extent and form of its lumen, the *gray matter* of the developing cord markedly increases, especially behind where the posterior horn appears as a projection beneath the broadening mass of the ingrowing dorsal root-fibres. As the *posterior horn* becomes better defined, the root-bundle becomes meso-laterally displaced, lying behind the horn, and then constitutes the *tract of Burdach*. Goll's tract is formed somewhat later and at about the third month appears as a narrow wedge-shaped area that is introduced between the mid-line and Burdach's tract. Towards the end of the second month, the *anterior white commissure* is indicated by the oblique transverse ingrowth of axones into the most ventral part of the floor-plate as they make their way to the opposite side. Meanwhile the anterior median fissure has

FIG. 906.



Developing spinal cord of about seven and one-half weeks. × 44. (*His.*)

FIG. 907.



Developing spinal cord of about three months. × 30. (*His.*)

become deeper and narrower in consequence of the increased bulk of medio-ventral parts of the cord. As the fissure is thus differentiated the process of mesoblastic tissue, which from the earliest suggestion of the groove occupies the depression, is correspondingly elongated and affords a passage for the blood-vessels destined for the nutrition of the interior of the cord. Until the third month the gray matter, derived from the nuclear layer, is much more voluminous than the surrounding marginal layer, which, so far as the contribution of nervous elements is concerned, is passive, since its conversion into the white matter depends upon the ingrowth of axones from the neurones situated either within or outside the cord.

The *development of the individual fibre-tracts* includes two stages, between the completion of which a considerable, and sometimes a long, period intervenes. The first marks the invasion of the supporting tissue of the marginal zone by the ingrowing axones as naked axis-cylinders; the second witnesses the clothing of these fibres with myelin. The period between the appearance of the tract and the development of the medullary coat is variable. In some cases, as in the great cerebro-spinal motor paths, although the fibres grow into the cord during the fifth month of fœtal life, myelination does not begin until shortly before birth and is not completed until after the second year. In other cases, as in the direct cerebellar, a period of three months, from the third to the sixth, elapses. It is probable that the acquisition of the medullary coat commences before the functional activity of the fibres begins, although such stimulation undoubtedly assists; further myelination proceeds gradually along the course of the fibres and in the direction of conduction.

Based on the observations of Flechsig, His, Bechterew, and others, the time of the appearance and of the development of the medullary coat of some of the fibres within the spinal cord may be given.

Fibres of	Appear	Myelinate
Anterior root	about 4th week	during 5th month
Burdach's tract	during 4th week	end of 6th month
Goll's tract	about 9th week	beginning of 7th month
Pyramidal tracts	end of 5th month	9th month to 2nd year
Direct cerebellar tract	beginning of 3rd month	about 6th month
Gowers' tract	during 4th month	during 6th month

The presence of the *sinus terminalis* (page 1030) in the cord at birth depends partly upon the persistence of the lumen of the central canal at the lower end of the conus medullaris and partly upon a proliferation of the wall-cells of the subjacent segment, followed by secondary dilatation shortly before birth.

During the early weeks of development, the neural tube extends to the lowermost limits of the series of somites; but after differentiation of the root-fibres begins, the segment of the cord below the level of origin of the first coccygeal nerves is marked by feeble proliferation, the effects of which are soon manifest in the rudimentary condition of the caudal end of the cord. With the subsequent development of the other regions, this histological contrast becomes more evident, to which is soon added the conspicuous attenuation caused by the attachment of the lower end of the cord to the caudal pole of the spine, which elongates with greater rapidity than the contained nervous cylinder. In this manner the lowest segment of the cord, with its mesoblastic envelope, is converted into the delicate thread-like *filum terminale*, within whose upper half are found the remains of the rudimentary nervous tissue.

PRACTICAL CONSIDERATIONS: SPINAL CORD.

Congenital Errors in Development.—The spinal cord may be absent (*amyelia*), or it may be defective in a certain portion (*atelomyelia*). In such conditions, however, the patient cannot live. The cord may be double from bifurcation (*diplomyelia*).

A *spina bifida* is a congenital condition due to a deficiency in the vertebræ, almost always of the laminæ and spinous processes. There is usually a protrusion of the contents of the spinal canal, although in some cases there is no protrusion, and in others the vertebral canal, or even the central canal of the cord may be open to the surface. Three varieties of tumors are described according to their contents. If the meninges only protrude from the canal in the form of a sac containing cerebro-spinal fluid, it is called a *meningocele;* if the sac contains a portion of the cord also it is called a *meningo-myelocele*. In the third variety, *syringo-myelocele*, the cavity of the tumor is found to consist either of the dilated canal of the cord, so that the thinned-out substance of the cord is in the wall of the sac, or of a cavity in the cord tissue itself. This is the least common of the three forms.

In the *meningo-myelocele*, which is the most common form, the cord becomes flattened out and attached to the posterior wall of the sac, but still has its central canal intact. The spinal nerves cross the sac to their corresponding intervertebral foramina. In this and in the syringo-myelocele there is frequently some degree of paralysis in the parts below from disturbance of the cord at the seat of the tumor. The most common seat of the defect is in the lumbo-sacral region. It is rare in other parts of the spine. Therefore, the bowels, bladder, and lower extremities are the parts most frequently affected. If the lesion is confined to the lower part of the sacral region, the extremities usually escape. Paralytic talipes is comparatively common.

There is no sharp line of demarcation between the medulla oblongata and the cord. The beginning of the latter is variously given as at the origin of the first cervical nerve, the lower margin of the foramen magnum, or the decussation of the pyramids, the last being the more generally accepted.

Since in the adult, the spinal cord ends below usually at the level of the disc between the first and second lumbar vertebræ, injuries of the spine below the second lumbar vertebra do not involve the cord. The membranes of the cord, however, containing cerebro-spinal fluid extend as far as the second or third sacral vertebra, so that at this level injuries with infection may cause fatal meningitis.

The bony canal is lined with periosteum, unlike the cranium, in which the external layer of the dura mater serves that purpose. The spinal dura is separated from the posterior common ligament, the ligamenta subflava, and the periosteum by a fatty areolar tissue containing a plexus of veins. Extensive extradural hemorrhage may, therefore, occur without serious pressure on the cord. The blood tends to sink by gravity, and later may produce symptoms of compression. The dura is thick and strong and offers considerable resistance to the invasion of disease from without, even to tuberculosis with caries of the vertebræ, or to malignant tumors arising within the vertebræ. Infections outside the spinal column, as in abscess of the back, or bed sores, may extend along the communicating veins, giving rise to extradural abscess and perhaps to extensive meningitis.

The spinal cord, surrounded by cerebro-spinal fluid, hangs loosely within the dura, being attached to it only by the roots of the spinal nerves which receive investments from the dura as they pass outward, by the ligamenta denticulata, and by the delicate fibres of arachnoid tissue extending from the pia to the dura. The cord is, therefore, not frequently injured from external violence. The numerous articulations of the vertebræ and the elasticity of the ligaments and of the intervertebral discs permit the distribution of much of the force applied to the spine before it reaches the cord.

The greater part of the cerebro-spinal fluid is contained in the subarachnoid space, which communicates freely with the same space in the cranium, and is continuous with the ventricular fluid through the foramen of Majendie.

The cord is exposed to the danger of penetration by sharp instruments only from behind, but even here the overlapping of the laminæ and spinous processes offers an excellent protection. This protection is largely lacking above and below the atlas, and the risk there from such wounds is correspondingly greater. At lower levels in order that the canal may be reached, the vulnerating instrument must be directed in the line of the obliquity of the laminæ, which will vary in the different portions of the spine, being greatest in the dorsal region.

Concussion—shaking with molecular disturbance and without obvious gross lesion—of the cord, although more frequent than has been supposed, is rare because of (*a*) the arrangement of the different constituents of the vertebral column, which by means of its curves, the elastic intervertebral discs, its numerous joints, and the large amount of cancellous tissue in the vertebral bodies, is able to take up and distribute harmlessly forces of some degree of violence ; (*b*) the situation of the cord in the centre of the column, where, as the most frequent serious injuries to the spine are caused by extreme forward flexion, it is somewhat removed from danger in accordance with a law of mechanics that "when a beam, as of timber, is exposed to breakage and the force does not exceed the limits of the strength of the material, one division resists compression, another laceration of the particles, while the third, between the two, is in a negative condition" (Jacobson) ; (*c*) the suspension of the cord in the surrounding cerebro-spinal fluid ("like a caterpillar hung by a thread in a phial of water"—Treves) by its thecal attachments and nerve-roots ; (*d*) its connection above with the cerebellum, itself resting on an elastic "water-bed" which minimizes the transmission downward of violence applied to the cranium. Many of the cases reported as concussion are undoubtedly due to hemorrhage or other gross lesions of the cord.

Contusion of the cord may occur from sprains, as in forced flexion of the spine. The most frequent and most serious cases are those due to fracture-dislocations of the spine, the cord being more or less crushed between the upper and lower fragments. It is so delicate a structure that it may be thoroughly disorganized without evident injury to the membranes or alteration of its internal form. The paralysis of the parts below will be complete or partial according to whether the whole or only a part of the transverse section of the cord at the seat of injury is destroyed. Since when the lesion is complete everything supplied by the cord below the seat of the lesion is paralyzed, the higher the injury to the cord the greater the gravity of the case. When the atlas or axis is fractured and displaced the vital centres in the medulla are in danger and death may result immediately. The phrenic nerves which arise chiefly from the fourth cervical segment, but partly from the third and fifth segments, are also paralyzed and respiration ceases.

In *fracture-dislocations* of the spine it is the body of the vertebra which is most frequently fractured, the ligaments yielding posteriorly and permitting the dislocation. The fractured edges of bone are, therefore, in front of the cord; and, as the upper fragment passes forward, the anterior or motor portion of the cord is pressed and crushed against the sharp upper edge of the lower fragment. In partial transverse lesions of the cord the paralysis below the lesions affects, therefore, the motor columns of the cord more than the sensory columns which are in part posterior.

The most frequent seat of fracture-dislocation of the spine is in the thoraco-lumbar region (page 145). Fortunately, it is this variety which offers the best prognosis, since the cord ends usually just below the lower border of the first lumbar vertebra, and the cauda equina being more movable and tougher than the cord itself, it can better evade the encroachment on the canal, although in spite of these facts, it is not infrequently injured in such lesions. The bodies of the lumbar vertebræ are the largest and most cancellous, the intervertebral discs the thickest and most elastic, so that crushing of them occurs with less tendency to invade the canal and injure the cord than in any other portion of the spine.

In *caries* of the spine (Pott's disease) the lesion is situated in the bodies of the vertebræ, and therefore, in front of the cord. As the inflammatory exudate extends it will invade the spinal canal anteriorly, often producing an external pachymeningitis. The irritation and pressure resulting will again affect the motor portion of the cord, first producing a paralysis of motion in the parts below, varying in degree according to the amount of pressure on the cord. If sensation is impaired it is a later phenomenon and is due to greater pressure upon the cord, and in some cases to myelitis. The loss of motion is often the only effect produced. If the lower cervical region is involved by the lesion the phrenic nerves will escape paralysis, but the arms, trunk, bladder, rectum, and lower extremities will be affected. Since the intercostal and abdominal muscles are involved in the paralysis, breathing will be difficult and will depend upon the action of the diaphragm only. Thus as the lesion occurs at successively lower levels, the highest limits of the paralyzed area descend, and the expectation of life increases.

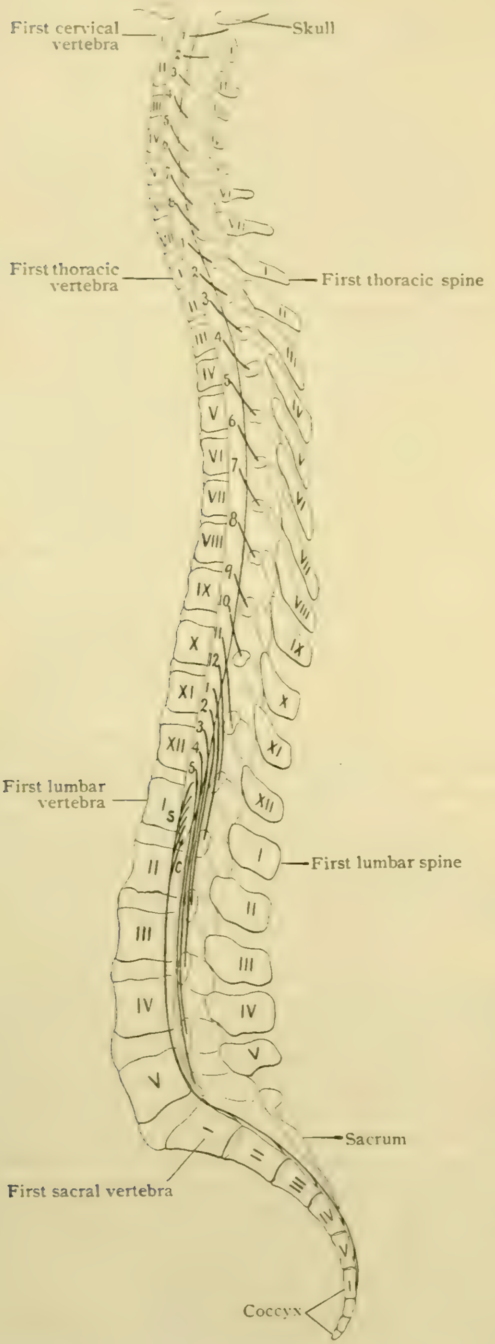
In the cervical and thoraco-lumbar regions where the injuries to the spine and the cord are most frequent, are situated the two enlargements of the cord. The cervical begins at the fourth cervical vertebra, gradually reaches its largest diameter opposite the fifth and sixth vertebræ, and then gradually decreases to the first thoracic, where it merges into the thoracic portion of the cord. Only in the thoracic region does the circumference of the cord remain the same throughout. The lumbar enlargement is shorter than the cervical and begins opposite the tenth thoracic vertebra, gradually increases to the twelfth thoracic, after which it gradually decreases to the conus medullaris.

The *localization* of *lesions* of the cord, producing symptoms of paralysis, will depend upon the height and extent of the paralyzed areas. It must be borne in mind that the nerve-roots arise from the cord usually at a level higher than the foramina through which they escape from the spinal canal. The first and second cervical nerve-roots pass out of the canal almost horizontally. The intraspinal course of the succeeding nerve-roots increases gradually in obliquity so that the spinous processes of the second, third and fourth vertebræ correspond approximately to the level of the third, fourth and fifth cervical nerve-roots. The seventh cervical spine corresponds to the first thoracic nerve-root. The spinous process of the fifth thoracic vertebra is on a level with the seventh thoracic nerve, and the spine of the tenth thoracic vertebra with the origin of the second lumbar nerve. The first lumbar nerve arises just below the ninth thoracic spine, the second lumbar nerve opposite the tenth thoracic spine, the third and fourth lumbar nerves opposite the eleventh spine, and the fifth lumbar and the first sacral nerves between the eleventh and twelfth thoracic spines.

Only the spinous processes can be our surface guides, and it must be borne in mind that they are not always on the level of their corresponding vertebræ. Briefly, it may be said that the eight cervical nerves arise from the cord between the lower margin of the foramen magnum and the sixth cervical spine, the first six thoracic

nerves between the latter spine and the fourth thoracic, the lower six thoracic nerves between the fourth and ninth dorsal spines, the five lumbar nerves opposite the ninth, tenth and eleventh spines, and the five sacral nerves opposite the twelfth thoracic and the first lumbar spine.

Fig. 908.



Diagram, based on frozen section, showing relations of bodies and spines of vertebræ to levels at which spinal nerves escape from vertebral canal.

A convenient rule to locate the levels of origin of the nerve-roots, applicable to the prelumbar nerves, is given by Ziehen as follows :—For the cervical nerves, subtract one from the number of the nerve, the remainder indicating the corresponding spinous process ; for the upper (I–V) thoracic nerves subtract one ; for the lower (VI–XII) thoracic nerves subtract two. All the cervical nerves pass out through the intervertebral foramina above the vertebræ after which they are named, except the eighth cervical, which emerges between the seventh cervical and the first dorsal vertebræ. All the other spinal nerves escape below the vertebræ from which they are named. Since the nerve-roots pass a considerable distance downward within the spinal canal before leaving it, it follows that a lesion of the cord at a given level, as from a fracture-dislocation of the spine, may be associated with a paralysis of the nerve-roots passing out at or below that level, and arising from the cord at a higher point. This must be taken into account in determining the seat of the lesion, since when the nerve-roots are not involved the lesion will be as much higher than its corresponding intervertebral foramina (as indicated by the upper limits of the paralyzed area) as the length of the intraspinal course of the corresponding nerve-roots.

Each root-cell in the anterior horn of gray matter is connected with a motor fibre, which passes out in the anterior root of a spinal nerve to its muscle. Motor impulses originating in the cortex of the brain, pass downward along the antero-lateral columns of the cord, chiefly in the lateral pyramidal tract. They first traverse the ganglion cells of the anterior horns before passing out in the anterior or motor roots to their destination. These ganglion cells constitute, at least functionally, the trophic centres for the muscles. Lesions of the anterior horns, therefore, besides causing

paralysis (*polio-myelitis*), will lead to atrophy of the corresponding muscles. The vasomotor centres are also in the anterior horns, probably in the intermedio-lateral tract.

Sensory impulses pass to the posterior horns through the posterior roots, and some of them soon cross to the opposite side of the cord, others ascending in the posterior column. The lemniscus is probably the chief sensory tract in the medulla oblongata, pons, and cerebral peduncles.

Every *segment* of the spinal cord contains centres for certain groups of muscles, and for reflex movements associated with them. A reflex begins in the stimulation of a sensory nerve. The impulse thus created passes to a centre in the cord and thence is transmitted to a motor nerve, thus producing a contraction of the muscle supplied by that nerve. The complete path of this impulse is called a *reflex arc*. The sensory impulse may be transmitted to different segments of the cord and thence out through the corresponding motor roots. Thus a complicated reflex arc is produced. It is to be assumed, however, that the impulse will take the shortest route, so that simple reflexes will have their reflex arc chiefly in those segments of the cord in which the posterior root enters.

Each segment of the cord is connected with fibres from the brain to which must be ascribed the function of reflex inhibition. If the inhibitory fibres are irritated, the reflexes are impaired from stimulation of inhibition. If the conductivity of these fibres is destroyed, the reflexes are increased; but if the reflex arc is broken at any point, the reflexes are lost. Among the most important of these are the skin and tendon reflexes.

The centres for the bladder, rectum, and sexual apparatus, are located in the sacral segment of the spinal cord at and below the third sacral segment. They regulate the functions of these organs and are associated in some unknown way with the brain. (See mechanics of urination, page 1914).

Hæmato-rhachis, or hemorrhage into the membranes of the cord (extramedullary hemorrhage), may result from an injury to the spinal column, as a fracture or a severe sprain. The bleeding may be from the plexus of veins between the dura and bony wall of the canal (most frequent), or from the vessels between the dura and the cord. In either case the symptoms will be much the same. There will be a sudden and severe pain in the region of the spine, diffused some distance from the seat of the injury, due to irritation of the meninges, and pain transferred along the distribution of the sensory nerves coming from the affected segments of the cord, accompanied by abnormal sensations, as tingling and hyperæsthesia. In the motor distribution there will be muscular spasm, or sometimes a persistent contraction of the muscles. General convulsive movements, retention of urine, and, later, symptoms of paralysis may appear, but as a rule the latter is not complete.

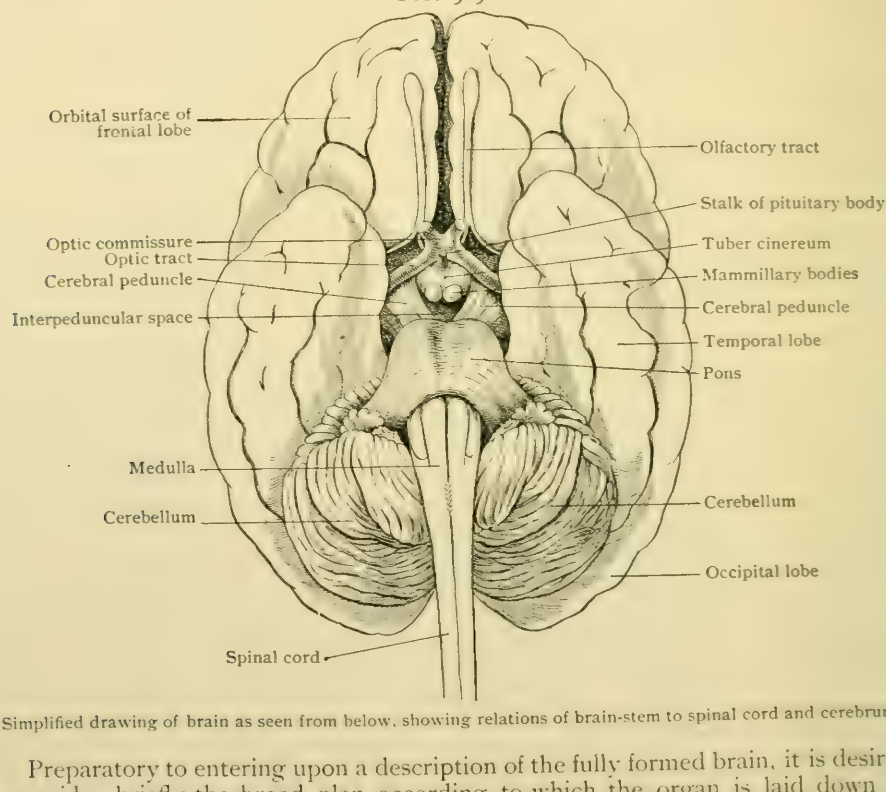
Hæmato-myelia, or hemorrhage into the substance of the cord (intramedullary hemorrhage) from traumatism, usually occurs between the fourth cervical segment of the cord and the first dorsal (Thorburn), and is commonly due to forced flexion of the spine, which is most marked in this region, as in falls on the head and neck. The cord has been crushed in such accidents without fracture of the spine and with only temporary dislocation. The hemorrhage is usually chiefly in the gray matter and may be only punctate in size, or may be large enough to extend far into the white matter, or even outside the cord into the subarachnoid space. The symptoms usually appear immediately after the injury and are bilateral, suggesting a total transverse lesion. There will be much pain in the back, occasionally extending along the arms or around the thorax. Spasms, rigidity, and paralysis rapidly ensue, with loss of the reflexes in the segment of the cord involved. There may be the same dissociation of sensation as in syringomyelia when the hemorrhage is confined to the centre of the cord.

THE BRAIN.

The brain, or the *encephalon*, is the part of the cerebro-spinal axis that lies within the skull. It is produced by the differentiation of the cephalic segment of the neural tube. Although the brain is often of great relative bulk and high complexity, as in man and some other mammals, it must not be forgotten that the spinal cord is the

fundamental and essential part of the nervous axis and that the degree to which the brain is developed is, in a sense, accidental and dependent upon the necessities of the animal in relation to the exercise of the higher nervous functions. In the lowest vertebrates, the fishes, in which association of the impressions received from the outer world is only feebly exercised, those parts of the brain rendering such functions possible, as the cerebral hemispheres, are very imperfectly represented. On the other hand, in man, in whom the capacity for the exercise of the higher nervous functions involving association is conspicuous, the antero-superior parts of the brain, the *pallium*, as the regions particularly concerned are called, are so enormously developed that the human brain is thereby distinguished from all others. Whether of low or high development, all brains are evolved from certain fundamental parts, the *brain-vesicles*, differentiated in the head-end of the embryonic neural canal; the underlying conception of the brain, therefore, is that of a tube, bent and modified to a variable degree by the thickening, unequal growth and expansion of its walls. Even when most complex, as in man, the adult organ exhibits unmistakable evidences of subdivision corresponding more or less closely with the primary brain-vesicles, and contains spaces, the ventricles, that represent the modified lumen of these segments.

FIG. 909.



Simplified drawing of brain as seen from below, showing relations of brain-stem to spinal cord and cerebrum.

Preparatory to entering upon a description of the fully formed brain, it is desirable to consider briefly the broad plan according to which the organ is laid down and the general lines along which its evolution proceeds. Before doing so, however, it will be necessary to take a general survey of the relations of the several divisions composing the brain.

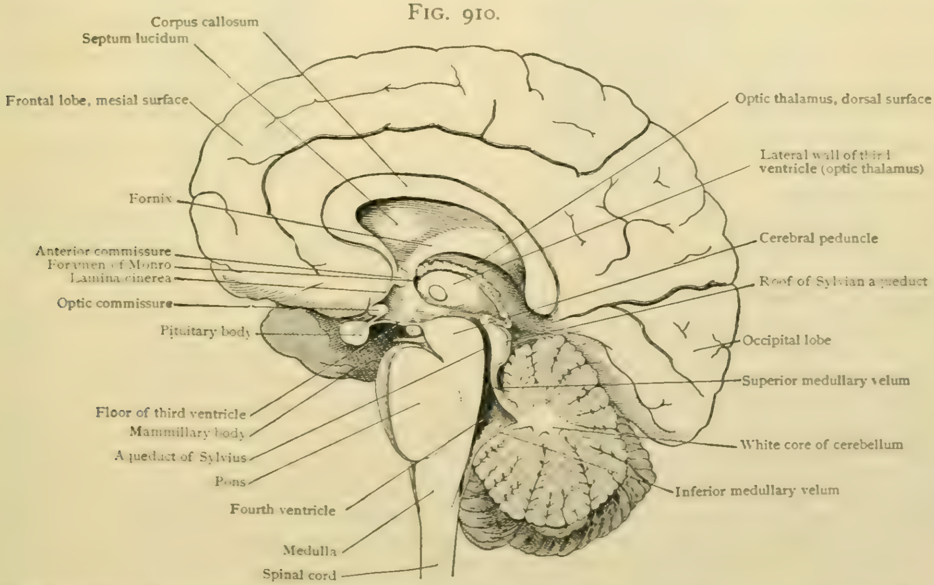
Denuded of its investing membranes and the attached cranial nerves, and viewed from below (Fig. 909), the encephalon is seen to consist of a median **brain-stem,** that inferiorly is directly continuous with the spinal cord through the foramen magnum and above divides into two diverging arms that disappear within the large overhanging mass of the cerebrum. The brain-stem includes three divisions, the inferior of which, the *medulla oblongata*, is the uninterrupted upward prolongation of the spinal cord and above is limited by the projecting lower border of the quadrilateral mass

of the next division, the *pons Varolii*. Beyond the upper margin of the pons the brain-stem is represented by a third division that ventrally is separated by a deep recess into two diverging limbs, the *cerebral peduncles*, or *crura cerebri*, to correspond with the halves or *hemispheres* of the **cerebrum**, each of which receives one of the crura and in this manner is connected with the lower levels of the cerebro-spinal axis. The greater part of the medulla and pons is covered dorsally by the **cerebellum**, whose large lateral expansions, or *hemispheres*, project on either side as conspicuous masses, distinguished by the closely set plications and intervening fissures that mark their surface. Of the five component parts of the brain—medulla, pons, cerebral peduncles, cerebrum, and cerebellum—the last two are coated with the cortical gray matter, in which, broadly speaking, are situated the neurones that constitute the end-stations for the sensory impulses conveyed by the various corticipetal paths and the centres controlling the lower-lying nuclei of the motor nerves. The brain-stem, on the other hand, whilst containing numerous stations for the reception and distribution of sensory impulses, is primarily the great pathway by which the cerebrum and the cerebellum are connected with each other and with the spinal cord.

Viewed in a mesial sagittal section (Fig. 910), each of these divisions is seen to be related to some part of the system of communicating spaces that, as the *lateral* and *third ventricles*, the *aqueduct of Sylvius* and the *fourth ventricle*, extend from the cerebral hemispheres above, through the brain-stem and beneath the cerebellum, to the *central canal* of the spinal cord below. Since the lateral ventricles are two in number, in correspondence with the cerebral hemispheres in which they lie, their position is lateral to the mid-plane and hence only one of the openings, the *foramina of Monro*, by which they communicate with the unpaired and mesially placed third ventricle, is seen in sagittal sections.

Both the roof and the floor of the irregular **third ventricle** are thin, whilst its lateral walls are formed by two robust masses, the *optic thalami*, the mesial surface

FIG. 910.



Simplified drawing of brain as seen in mesial section, showing relation of brain-stem, cerebrum and cerebellum, and ventricular spaces.

of one of which forms the background of the space when viewed in sagittal section. The *roof* of the ventricle is very thin and consists of the delicate layer of *ependyma*, as the immediate lining of the ventricular spaces is designated, supported by the closely adherent fold of pia mater which in this situation pushes before it the neural wall and contains within its lateral border a thickened fringe of blood-vessels, the

choroid plexus. The two structures, the ependyma and the pia mater together, constitute the membranous *velum interpositum* that forms the roof of the ventricle and lies beneath the triangular *fornix*, whose vaulted form is suggested by the arching ridge that descends in front of the thalamus and marks the position of the anterior pillar of the fornix. Behind, just over the upper end of the Sylvian aqueduct, lies the cone-shaped *pineal body* that belongs to the third ventricle, from which it is an outgrowth. The *floor* of the ventricle is also, for the most part, relatively thin and irregular in contour. It corresponds to the median part of the lozenge-shaped area, the *interpeduncular space*, which, seen on the inferior surface of the brain, is bounded behind by the anteriorly diverging cerebral peduncles and in front by the *optic chiasm* and the posteriorly diverging *optic tracts*. The posterior half of this area includes the deep triangular recess at the bottom of which are seen the numerous minute openings of the *posterior perforated space* through which small branches of the posterior cerebral arteries pass to the optic thalamus and the crura. Passing forward, the paired *corpora mammillaria*, the *tuber cinereum*, the stalk of the *pituitary body* occupy successively the interpeduncular space. Anteriorly, between the transversely cut optic chiasm below and the recurved portion of the great arching commissure, the *corpus callosum*, above, the third ventricle is closed by a thin sheet of nervous substance known as the *lamina cinerea*.

Through the foramina of Monro the lateral ventricles open into the third, and the latter communicates with the fourth ventricle by way of the Sylvian aqueduct. This narrow canal is surrounded below and laterally by the dorsal part or *tegmentum* of the cerebral peduncles ; above it lies a plate of some thickness the dorsal surface of which is modelled into two pairs of rounded elevations, the superior and inferior *corpora quadrigemina*.

In sagittal section, the **fourth ventricle** appears as a triangular space, the anterior or basal wall being formed by the dorsal surface of the pons and medulla and the posteriorly directed apex lying beneath the cerebellum. The upper half of the thin tent-like roof of the ventricle is formed by the *superior medullary velum*, a thin layer of white matter that stretches from beneath the inferior corpora quadrigemina to the cerebellum. A similar lamina, the *inferior medullary velum* extends from the cerebellum downward, but before reaching the dorsal surface of the medulla becomes so attenuated that this part of the ventricular roof, known as the *tela chorioidea*, consists practically of the pia mater, although the ependyma excludes the vascular membrane from actual entrance into the ventricle. The pia, however, pushes in the ependymal layer and in this manner produces the vascular fringes known as the *choroid plexus* of the fourth ventricle. When viewed from behind, the ventricle exhibits a rhomboidal outline, the lateral boundaries above being formed by two arms, the *superior cerebellar peduncles*, that divergingly descend from the sides of the corpora quadrigemina to the cerebellum. Similar bands, the *inferior cerebellar peduncles*, convergingly descend from the cerebellar hemispheres to the posterior columns of the medulla and form the lower lateral boundaries of the fourth ventricle.

Seen from directly above (Fig. 984), the **cerebrum**, divided into its hemispheres by the deep *sagittal fissure*, is the only part of the brain visible, the other four divisions being masked by the enormously developed overhanging cerebral mantle. The effects of this expansion in displacing base-ward parts which, temporarily in man and permanently in the lower vertebrates, occupy a superior position, are conspicuous when the sagittal section of the developing (Fig. 913) and that of the fully formed human brain (Fig. 910) are compared. It should be noted, that although in the latter the brain-stem and the cerebellum are completely overhung by the cerebral hemispheres, they still are in relation with the free surface of the brain, and by passing beneath the posterior part of the cerebrum the dorsal surface of the cerebellum and of the brain-stem may be reached without mutilation of the nervous tissue.

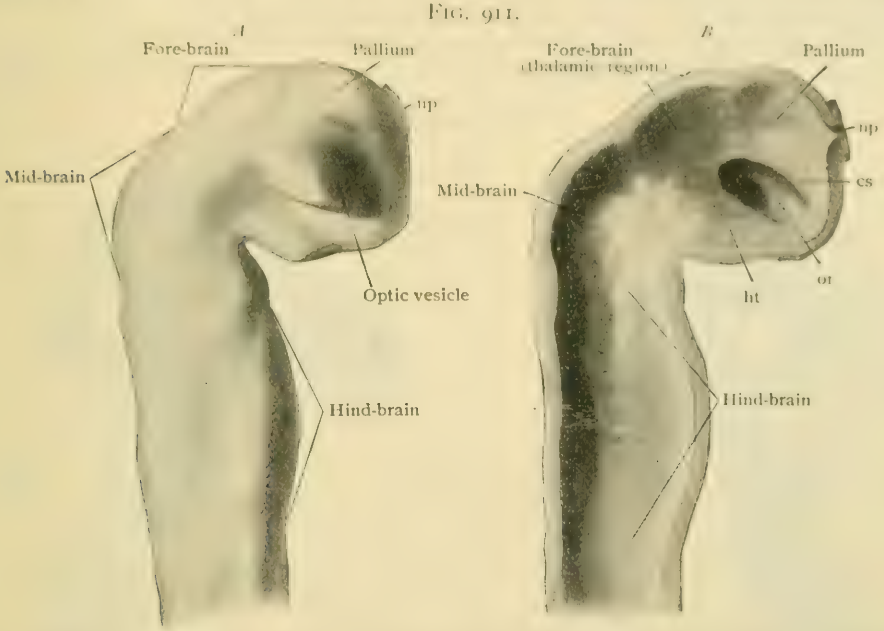
THE GENERAL DEVELOPMENT OF THE BRAIN.

Even before complete closure of the anterior end of the **neural tube**, which takes place probably shortly after the end of the second week of fœtal life, the cephalic region of this tube, slightly flattened from side to side, exhibits the results

of unequal growth in two slight constrictions separating three dilatations known as the **primary brain-vesicles**. The posterior of these, the **hind-brain**,[1] is much the longer, exceeding the combined length of the other two (Fig. 911); after a short time when viewed from behind it presents an elongated lozenge-shaped form and, hence, is also called the **rhombencephalon**. The middle vesicle, the **mid-brain**, or **mesencephalon**, is conspicuous on account of its rounded form and prominent position, lying, as it does, over the marked primary flexure which the head-end of the neural tube very early exhibits.

The anterior vesicle, known as the **fore-brain**, or **prosencephalon**, at first is small and rounded, but soon becomes modified by the appearance, on either side, of a hollow protuberance, the *optic vesicle*, that pushes out from the lower lateral wall. For a time the optic vesicle communicates with the main cavity of the fore-brain by a wide opening. This gradually becomes reduced and constricted until the

FIG. 911.



Reconstruction of brain of human embryo of about two weeks (3.2 mm.); *A*, outer surface; *B*, inner surface; *np*, neural pore, where fore-brain is still open; *cs*, anlage of corpus striatum; *or*, optic recess leading into optic vesicle; *ht*, hypothalamic region. (*His*.)

evagination is attached by a hollow stem, the *optic stalk*, which later takes part in the formation of the optic nerve that connects the eye with the brain, the vesicle itself giving rise (page 1482) to the nervous coat of the eye, the retina. By the time the optic evagination is formed, the front part of the fore-brain shows a slight bulging, narrow below and broader and rounded above, and separated from the optic outgrowth by a slight furrow. This is the first suggestion of the anlage of the hemisphere or *pallium* (His). The latter soon gives rise to two rounded hollow protrusions, one on either side of the fore-brain, that rapidly expand into the conspicuous *primary cerebral hemispheres*. The lower part of the fore-brain includes the region that later, after differentiation and outgrowth from the hemisphere, receives the nerves of smell and is known as the *rhinencephalon*.

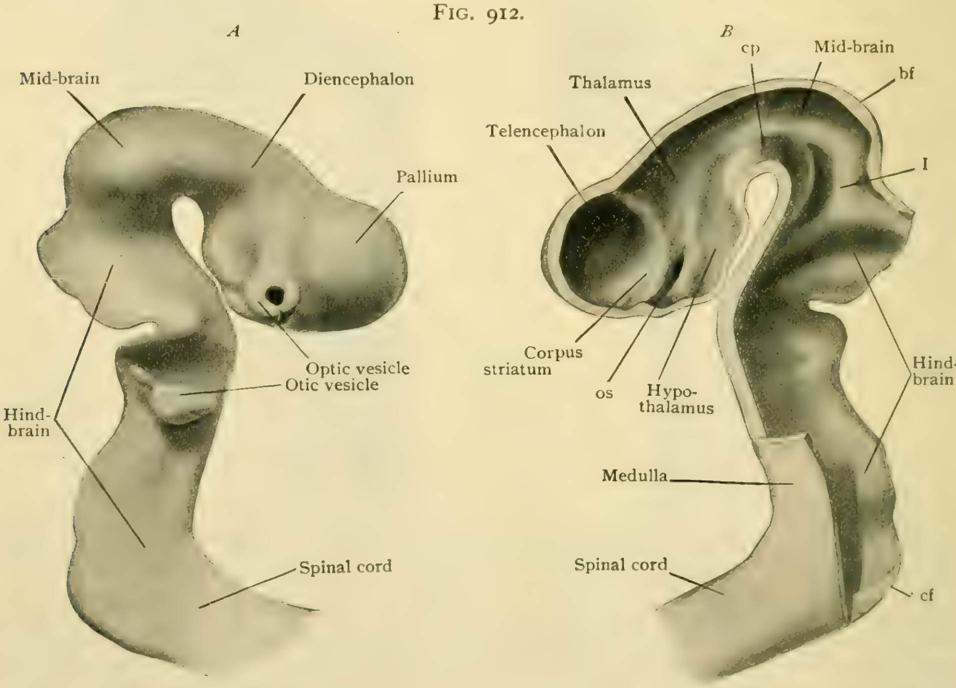
A slight ridge (Fig. 911, *B*), projecting inward from the roof of the fore-brain, suggests a subdivision of the general space into a posterior and an anterior region.

[1] This use of the term *hind-brain* is at variance with its older significance, still retained by some German writers, as indicating the upper division (metencephalon) of the posterior primary vesicle. In view, however, of the now general application of *fore-brain* and *mid-brain* to the other primary vesicles, it seems more consistent to include hind-brain in the series, as has been done by Cunningham, with a distinct gain not only in convenience, but in avoiding terms which in their Anglicised form are at best awkward and unnecessary.

The latter, the outwardly bulging pallium or hemisphere-anlage, is limited below by the *optic recess*, the entrance into the optic vesicle, and, farther front, by a flattened triangular elevation that marks the earliest rudiment of the *corpus striatum*. The posterior or *thalamic region* extends backward to the mid-brain, from which it is separated by the slight external constriction and corresponding internal ridge. During the fourth week the demarcations just noted become more definite, so that the primary anterior vesicle is imperfectly subdivided into two secondary compartments, the **telencephalon,** conveniently called the *end-brain*, and the **diencephalon.** Considered with regard to the details presented by the interior of the fore-brain, the four areas recognized by His are evident. These are (Fig. 912) the region of the *pallium* and of the *corpus striatum*, respectively above and below in the telencephalon, and the region of the *thalamus* and of the *hypothalamus* respectively above and below in the diencephalon. Between the protruding hemispheres, the telencephalon is closed in front and below by a thin and narrow wall, the *lamina terminalis*, which defines the anterior limit of the brain-tube.

While the more detailed account of the further development of these regions will be given in connection with the description of the several divisions of the brain,

FIG. 912.



Reconstruction of brain of human embryo of about four weeks (6.9 mm.); A, outer surface; B, inner surface; *I*, isthmus; *os*, aperture of optic stalk; *cp*, cerebral peduncle; *cf*, cervical flexure; bf, cephalic flexure. Drawn from His model.

it may be pointed out here, in a general way, that the pallium gives rise to the conspicuous cerebral hemispheres, which, joined below by a common lamina, expand outward, upward and backward and rapidly dwarf the other parts of the brain-tube which are thus gradually covered over. The striate area thickens into the corpus striatum, which appears as a striking prominence on the outer and lower wall of each lateral ventricle. The latter represents a secondary extension of the original cavity of the fore-brain enclosed by the developing cerebral hemisphere, and at first is large and thin-walled and communicates by a wide opening with the remainder of the brain-vesicle. The unequal growth and thickening, which subsequently modify the surrounding walls, reduce this large aperture until it persists as the small foramen of Monro, by which the lateral ventricle communicates with the third ventricle. The latter represents what is left of the cavity of the fore-brain and, therefore, the com-

bined contribution of the telencephalon and diencephalon. During the fifth week the diencephalon expands into a relatively large irregular space (Fig. 913), whose roof and floor are thin and whose lateral walls are thickened by the masses of the developing thalami. The hypothalamic region becomes the most dependent part of the fore-brain and gives rise to the structures that later occupy the interpeduncular space on the base of the brain. The roof of the diencephalon remains thin, does not produce nervous tissue and, in conjunction with the ingrowth of the vascular pia mater, forms the velum interpositum and its choroid plexuses. The pineal body and the posterior lobe of the pituitary body arise as outgrowths from the roof and floor of the diencephalon respectively.

The **mid-brain,** or **mesencephalon**, at first large and conspicuous on account of its elongation and prominent position at the summit of the brain-tube, does not keep pace with the adjoining vesicles, and in the fully formed brain is represented by the parts surrounding the aqueduct of Sylvius. Neither does it subdivide, but, while its entire wall is converted into nervous tissue, retains its primary simplicity to a greater degree than any of the other brain-segments. The lateral and ventral walls of the mid-brain contribute the cerebral peduncles ; its roof gives rise to the corpora quadrigemina ; and its cavity persists as the narrow canal, the aqueduct of Sylvius, that connects the third and fourth ventricles.

The posterior vesicle, the **hind-brain,** or **rhombencephalon**, the largest of the primary brain-segments, is the seat of striking changes. These include thickening and sharp forward flexion of the ventro-lateral walls, in consequence of which the floor of the space becomes broadened out opposite the bend and assumes a lozenge-shaped outline. The hind-brain is conventionally subdivided (Fig. 913) into a superior part, the **metencephalon,** and an inferior part, the **myelencephalon.** Its cavity, common to both subdivisions, persists as the fourth ventricle.

The extreme upper part of the **metencephalon,** where it joins the mid-brain, early exhibits a constriction, which by His has been termed the **isthmus rhombencephali** and regarded as a distinct division of the brain-tube. In the fully formed brain, the isthmus corresponds to the uppermost part of the fourth ventricle, just below the Sylvian aqueduct, roofed in by the superior medullary velum that stretches between the superior cerebellar peduncles. The thickened and markedly bent ventro-lateral wall of the metencephalon gives rise to the pons Varolii, whilst in the roof of the ventricle appears a new mass of nervous tissue, the cerebellum.

The **myelencephalon**, soon limited below by the cervical flexure, shares in the ventral thickening seen in the preceding division. Its floor and particularly its sides, the latter at the same time spreading apart, form the medulla oblongata, which below gradually tapers into the spinal cord. Its roof, in which thinness is always a prominent feature, becomes more attenuated as development proceeds and is converted into the inferior medullary velum and the tela chorioidea that close in this part of the fourth ventricle. The subsequent invagination of this membranous portion of the ventricular roof by the pia mater brings about the production of a choroid plexus similar to that seen in the roof of the third ventricle.

From the foregoing sketch of the changes affecting the embryonic brain-tube, it is evident that the anterior and posterior primary vesicles undergo subdivision, while the mid-brain remains undivided, five **secondary brain-vesicles**—the telencephalon, the diencephalon, the mesencephalon, the metencephalon and the myelencephalon—replacing the three primary ones.

In consequence of the unequal growth of various parts of the cephalic segment of the neural tube, the latter becomes bent in the sagittal plane at certain points, so that, when viewed from the side, the axis of the developing human brain describes an S-like curve (Fig. 912). These flexures, to which incidental reference has been made, bring about a disturbance, for the most part temporary, in the relations of the brain-segments, which in the lower vertebrates follow in regular order along an axis practically straight. In the developing human brain, in which they are most conspicuous, there are three flexures—the cephalic, cervical, and pontile.

The first of these, the **cephalic flexure** which appears towards the end of the second week and before the neural tube has completely closed, is primary and involves the entire head. It takes place in the region of the mid-brain and lies

above the anterior end of the primary gut-tube and of the notochord. At first the axis of the fore-brain lies about at right angles with that of the rhombencephalon, (Fig. 911) but, with the increasing size of the middle and anterior vesicles, the angle of the flexure becomes more acute until the long axis of the fore-brain and of the rhombencephalon are almost parallel (Fig. 912).

Fig. 913.

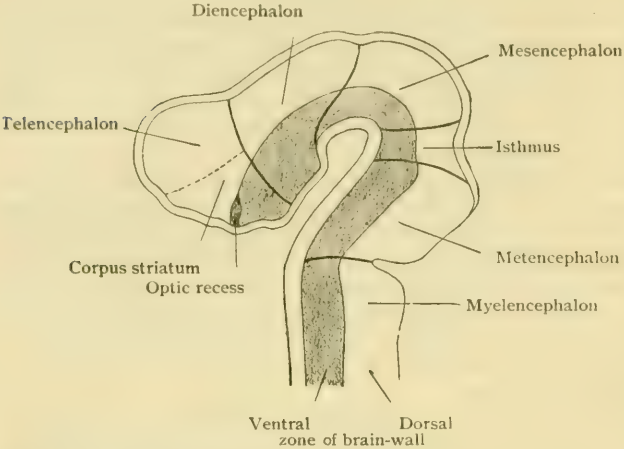


Diagram showing five cerebral vesicles and dorsal and ventral zones of their wall; based on brain of embryo of four and one-half weeks. (*His.*)

During the fourth week a second ventral bend, the **cervical flexure,** appears at the lower end of the hind-brain and marks the separation of the encephalic from the spinal portion of the neural tube. The cervical flexure, which also involves the head, is most evident at the close of the fourth week, when it is almost a right angle (Fig. 912); after this it becomes less pronounced in consequence of the elevation of the head which succeeds the period when the embryonic axis is most bent.

The third flexure appears about the fifth week in the part of the metencephalon in which the pons is later developed and, hence, is termed the **pontile flexure.** It concerns chiefly the ventral wall, which is in consequence for a time ventrally doubled on itself; subsequently this flexure almost entirely disappears. In contrast to the preceding bends, this flexure is only partial and involves chiefly the ventral and only slightly the dorsal wall of the neural tube; on the exterior of the embryo its presence is not detectable.

The developmental relations of the chief parts of the fully formed brain to the embryonic brain-vesicles are shown in the accompanying table.

Table Showing Relations of Brain-Vesicles and Their Derivatives.

Primary Segment	Secondary Segment	Derivatives	Cavity
Anterior vesicle **Prosencephalon** or Fore-brain	Telencephalon	Cerebral hemispheres Olfactory lobes Corpora striata	Lateral ventricles } secondary Foramina of Monro } Anterior part of third ventricle
	Diencephalon	Optic thalami Optic nerves and tracts Subthalamic tegmenta Interpeduncular structures Pineal and pituitary bodies	Posterior part of third ventricle
Middle vesicle **Mesencephalon** or Mid-brain	Mesencephalon	Cerebral peduncles Corpora quadrigemina	Aqueduct of Sylvius
Posterior vesicle **Rhombencephalon** or Hind-brain	Isthmus	Superior cerebellar peduncles Superior medullary velum	Fourth ventricle
	Metencephalon	Pons Cerebellum	
	Myelencephalon	Medulla Inferior medullary velum	

Notwithstanding the great changes in position and relation which many parts of the human brain suffer during development, chiefly in consequence of the enormous expansion of the pallium and the correspondingly large size of its commissure, the

corpus callosum, the fundamental relationships indicated by embryology are of such value that, even in the description of the adult organ, grouping of the various parts of the brain upon a developmental basis is found advantageous. Although strict adherence to such a plan would be at times inconvenient, and, therefore, will not be followed, constant reference to primary relations is imperative. It will be convenient, therefore, at this place, to call attention to the accompanying outline diagrams which illustrate the principles established by His in his epoch-making studies of the human brain. In addition to showing the five cerebral vesicles, Fig. 913 indicates the relative position and extent of the two fundamental subdivisions of the lateral walls of the neural tube, the *dorsal* or *alar* and the *ventral* or *basal* laminæ, which play such important rôles in the differentiation of the various parts of the brain-stem. Fig. 914 shows a later stage, in which the genetic relations of all the more important parts of the brain may be recognized. The greatest complexity is presented in the development of the derivations of the fore-brain, particularly of those which are differentiated from the diencephalon and later are found connected with the third ventricle. In order to set forth the developmental relations of the fore-brain, the following table from His, slightly modified, will be of service:

FIG. 914.

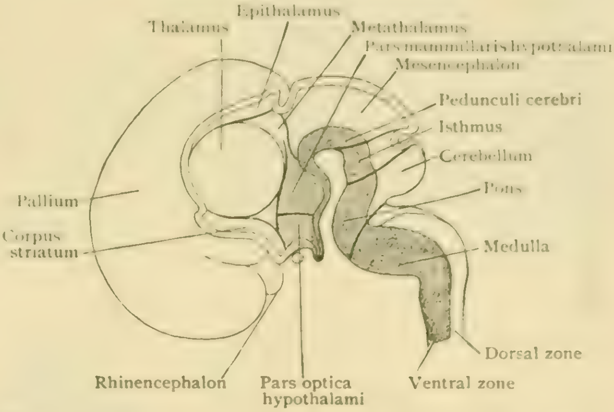


Diagram showing chief derivatives from cerebral visicles; based on brain of embryo of third month. (*His.*)

Fore-Brain or **Prosencephalon**	TELENCEPHALON	Hemisphærium	Pallium	
			Corpus striatum	
			Rhinencephalon	
		Pars optica hypothalami		
	DIENCEPHALON	Pars mammillaris hypothalami		
		Thalamencephalon	Thalamus	
			Epithalamus	Habenula
				Corpus pineale
				Commissura post.
			Metathalamus	Corpora geniculata

PARTS OF THE BRAIN DERIVED FROM THE RHOMBENCEPHALON.

THE MEDULLA OBLONGATA.

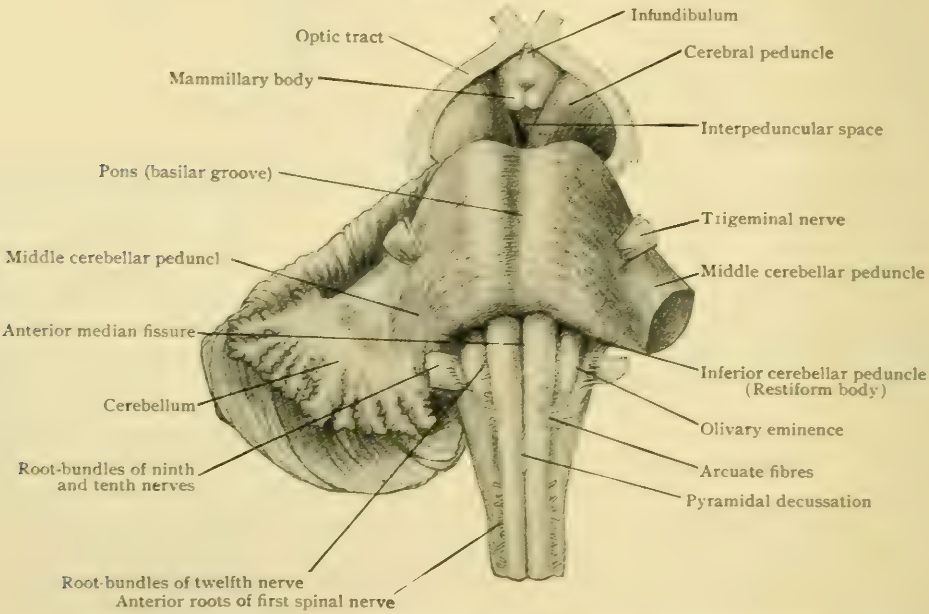
The medulla oblongata, sometimes called the *bulb* and usually designated by the convenient but indefinite name "medulla," is the direct upward prolongation of the spinal cord. It begins at the decussation of the pyramids below, about on a level with the lower border of the foramen magnum, and ends at the lower margin of the pons above and is approximately 2.5 cm. (1 in) in. length. Its general form is tapering, increasing in breadth from the transverse diameter of the cord (10 mm.) below, to almost twice as much (18 mm.) above, and in the antero-posterior dimension from 8–15 mm. Its long axis corresponds very closely with that of the cord and is, therefore, approximately vertical. The medulla, surrounded by the pia and arachnoid, lies behind the concave surface of the basilar portion of the occipital bone, with its dorsal surface within the vallecula between the hemispheres of the cerebellum.

Superficially, in many respects the medulla appears to be the direct continuation of the spinal cord. Thus, it is divided into lateral halves by the prolongation of the anterior and posterior median fissures; each half is subdivided by a ventro-lateral and a dorso-lateral line of nerve-roots into tracts that seemingly are continuations of

the anterior, lateral and posterior columns of the cord. This correspondence, however, is incomplete and only superficial, since, as will be evident after studying the internal structure of the medulla, the components of the cord, both gray and white matter, are rearranged or modified to such an extent that few occupy the same position in the medulla as they do in the cord.

The **anterior median fissure** is interrupted at the lower limit of the medulla, for a distance of from 6–7 mm., by from five to seven robust strands of nerve-fibres that pass obliquely across the furrow, interlacing as they proceed from the two sides. These strands constitute the **decussation of the pyramids** (**decussatio pyramidum**), whereby the greater number of the fibres of the important motor paths pass to the opposite sides to gain the lateral columns of the cord, in which they descend as the lateral pyramidal tracts. The fibres that remain uncrossed occupy the lateral portions of the pyramids and, converging towards the median fissure, descend on either side of the latter within the anterior columns as the direct pyramidal tracts. The

FIG. 915.



Brain-stem viewed from in front, showing ventral aspect of medulla, pons and mid-brain.

decussation varies in distinctness, sometimes the component strands being so buried within the fissure that they are scarcely evident, or even not at all apparent, on the surface and can be satisfactorily seen only when the lips of the groove are separated.

Above the decussation the anterior median fissure increases in depth in consequence of the greater projection of the bounding pyramidal tracts. Its upper end, just below the inferior border of the pons, is marked by a slightly expanded triangular depression, the *foramen cæcum.*

The **posterior median fissure**, the direct continuation of the corresponding groove on the cord, extends along only the lower half of the medulla, since above that limit it disappears in consequence of (*a*) the separation and divergence of the dorsal tracts of the bulb, which below enclose the fissure, to form the lower lateral boundaries of the lozenge-shaped fourth ventricle (**fossa rhomboidalis**), and (*b*) the gradual backward displacement of the central canal within the closed part of the medulla until, at the lower angle of the ventricle, it opens out into that space.

Each half of the medulla is superficially subdivided into three longitudinal tracts or **areas** by two grooves situated at some distance to the side of the ventral and dorsal median fissures respectively. One of these, the **antero-lateral furrow,** marks the line of emergence of the root-fibres of the hypoglossal nerve, which, being entirely

motor, correspond to the ventral roots of the spinal nerves with which they are in series. The other groove, the **postero-lateral furrow**, continues upward in a general way the line of the dorsal spinal root-fibres and marks the attachment of the fibres of the ninth, tenth and bulbar part of the eleventh cranial nerves. Unlike the posterior root-fibres of the cord, which are exclusively sensory, those attached along this groove of the medulla are partly efferent and partly afferent, the fibres belonging to the spinal accessory being entirely motor, while those of the glosso-pharyngeal and the pneumogastric include both and, therefore, are mixed.

The Anterior Area.—This subdivision of the medulla, also known as the *pyramid*, includes the region lying between the anterior median fissure and the antero-lateral furrow. Superficially it appears as a slightly convex longitudinal tract, from 6–7 mm. in width, that continues upward the anterior column of the cord. Each pyramid constitutes a robust strand, which below begins at the decussation and, increasing slightly as it ascends, above disappears within the substance of the pons. Just before its disappearance, or, strictly speaking, after its emergence, the pyramid is slightly contracted on account of the increased width of the bounding furrows. Its chief components being the descending motor paths formed by the cortico-spinal fibres, of which approximately four-fifths pass to the opposite side by way of the decussation to gain the lateral pyramidal tract, it is evident that only to the extent of the direct pyramidal fasciculus and, for a short distance, the anterior ground-bundle, are its constituents represented in the anterior column of the spinal cord.

FIG. 916.

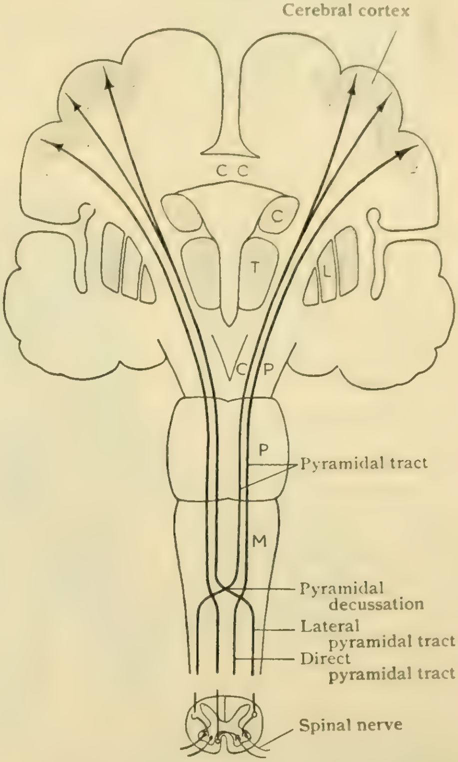


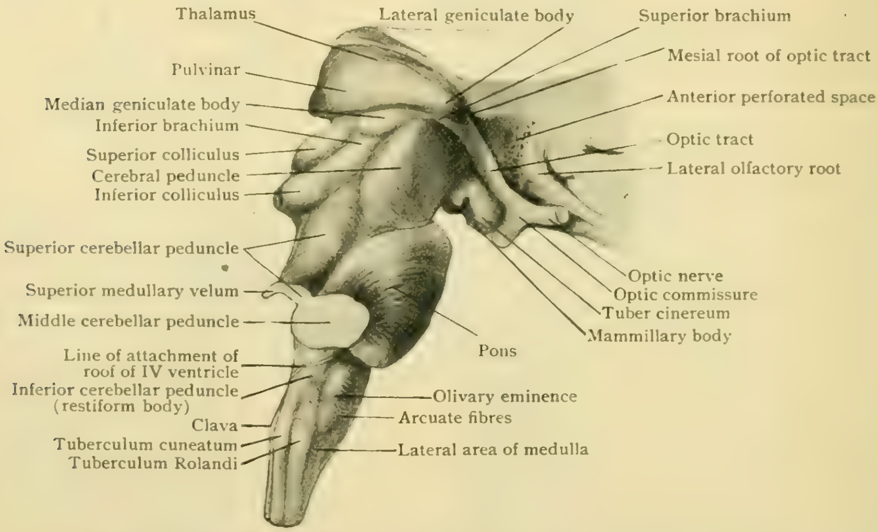
Diagram showing course and decussation of cortico-spinal (pyramidal) tract; M, medulla; P, pons; CP, cerebral peduncle; T, thalamus; C, L, caudate and lenticular nuclei; CC, corpus callosum.

The fibres destined for the direct pyramidal tract, which above the decussation occupy the lateral part of the pyramid, gradually converge toward the mid-line as the decussating fibres disappear, until, at the lower limit of the crossing, they lie next the median fissure, which position they retain in their further descent within the cord. The space thus afforded at the lower end of the medulla, to the outer side of the uncrossed fibres, is occupied by the prolongation of the anterior ground-bundle, which, however, soon suffers displacement as it encounters the pyramid. The ground-bundle lies at first to the outer side of the strands of decussating fibres and then behind the pyramid; higher, it is pushed backward towards the mid-line by the appearance of the inferior olive and the mesial fillet until, finally, it is continued as the posterior longitudinal fasciculus at the side of the median raphe beneath the gray matter covering the floor of the fourth ventricle.

The proportion of the pyramidal fibres taking part in the motor decussation is not always the same, from 80–90 per cent. being the usual number. Very rarely all the fibres cross, with suppression of the direct pyramidal tracts—an arrangement found normally in many lower animals. On the other hand, the direct pyramidal tracts may appropriate an unusually large number of the fibres, even to 90 per cent. of the entire pyramid, the crossed tract, however, never being entirely unrepresented. Ordinarily the tracts of the two sides are approximately of equal extent, but occasionally they may be asymmetrical, in which case the excess of the one is offset by a corresponding diminution in the fasciculus of the opposite side (Flechsig).

The Lateral Area.—This region is defined on the surface by the antero-lateral and postero-lateral furrows in front and behind respectively, and includes a narrow strip on the lateral aspect of the medulla. Below, the tract is continuous with the lateral column of the cord, a resemblance which is, however, only superficial since within the medulla the large crossed pyramidal tract no longer lies laterally but within the anterior area of the opposite side. The upper part of the lateral area is conspicuously modified by the presence of an elongated oval prominence, the **olivary eminence** (oliva), produced by the underlying corrugated lamina of gray matter composing the inferior olivary nucleus. The olive measures about 13 mm. in length and about half as much in its greatest width. Its upper end, more prominent and slightly broader than the lower, is separated from the inferior border of the pons by a deep groove, which medially joins the furrow occupied by the hypoglossal root-fibres and laterally is continuous with a broad depressed area, the *paraolivary fossa*, that separates the olive from the restiform body and lodges the fibres of the glosso-pharyngeal and pneumogastric nerves. The demarcation of the lower tapering end of the olive is somewhat masked by the *anterior superficial arcuate fibres*, which cover for a variable distance the inferior part of the olive in their course backward to gain

FIG. 917.



Brain-stem viewed from the side, showing lateral aspect of medulla, pons, and mid-brain.

the restiform body. The components of the lateral column of the cord traceable into the medulla—the direct cerebellar and Gowers' tract and the long paths of the lateral ground-bundle—for the most part, with the exception of the direct cerebellar tract, pass beneath or to the outer side of the olive. The superficially placed direct cerebellar tract gradually leaves the lateral area and passes outward and backward to join the inferior cerebellar peduncle by which it reaches the cerebellum.

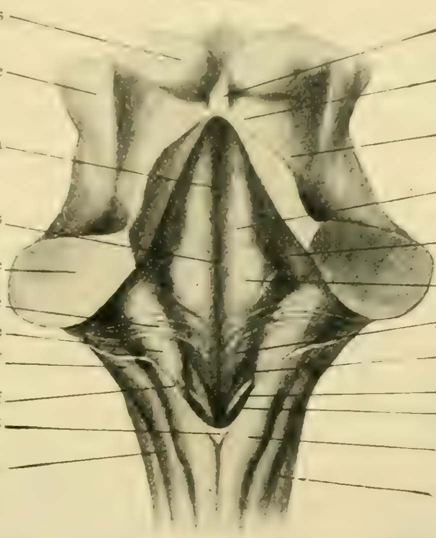
The Posterior Area.—The posterior region of the medulla is bounded laterally by the fibres of the ninth and tenth nerves; and mesially, in the lower half of the bulb, by the posterior median fissure and, in the upper half, by the diverging sides of the fourth ventricle. Below, the posterior area receives the prolongations of the tracts of Goll and of Burdach, which within the medulla are known as the **funiculus gracilis** and **funiculus cuneatus** respectively, and are separated from each other by the paramedian sulcus. Beginning with a width of about 2 mm., the gracile funiculus increases in breadth as it ascends until, just before reaching the lower end of the fourth ventricle, it expands into a well-marked swelling, the **clava,** about 4 mm. wide, which is caused by a subjacent accumulation of gray matter. Then, diverging from its fellow of the opposite side to bound the ventricle, after a short course it loses its identity as a distinct strand and becomes continuous with the

inferior cerebellar peduncle or **restiform body**. The expansion within the upper part of the funiculus gracilis, the clava, contains the **nucleus gracilis** (nucleus funiculi gracilis), the reception station in which the long sensory fibres of Goll's tract are interrupted. The triangular interval included between the gracile funiculi, where these begin to diverge, corresponds to the level at which the central canal of the cord ends by opening out into the fourth ventricle. A thin lamina, the **obex**, closes this interval and is continuous with the ventricular roof.

Along the outer side of the gracile fasciculus and separated from it by the paramedian furrow, extends a second longitudinal tract, the **funiculus cuneatus**, which at the lower end of the medulla receives the column of Burdach. Slightly above the lower level of the clava, the cuneate strand also exhibits an expansion, the **cuneate tubercle** (tuberculum cuneatum), that is less circumscribed, but extends farther upward than the median elevation. Beneath this prominence lies an elongated mass of gray matter, the **nucleus cuneatus** (nucleus funiculi cuneati), around whose cells the long sensory fibres of Burdach's tract end.

Still more laterally, between the roots of the ninth and tenth nerves and the cuneate strand, the posterior area of the medulla presents a third longitudinal elevation, the **funiculus of Rolando**. The latter is caused by the increased bulk of the

FIG. 918



Medulla and floor of fourth ventricle seen from behind, after removal of cerebellum and ventricular roof. × 1½.

underlying substantia gelatinosa that caps the remains of the posterior horn of gray matter, and is overlaid by a superficial sheet of white matter composed of the longitudinal fibres of the descending root of the trigeminal nerve. While, therefore, the tubercle of Rolando is produced by the exaggeration of gray matter represented within the spinal cord, the gracile and cuneate nuclei are new stations in which the posterior root-fibres not interrupted at lower levels end, and from which the sensory impulses collected by the cord are distributed to the cerebellum and the higher centres by neurones of the second order.

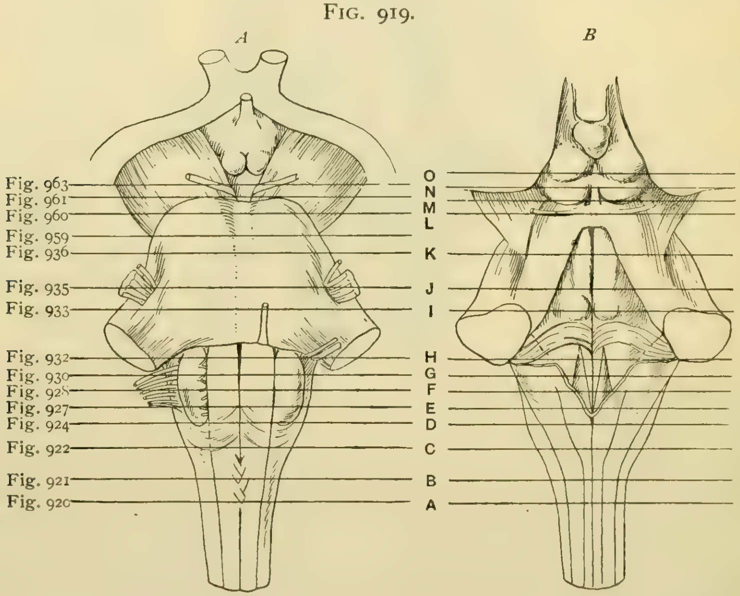
The upper half of the posterior area of the medulla is modified by the presence of the fourth ventricle, the lower lateral boundary of which it largely forms, into a robust rope-like strand that diverges as it ascends. Above, it abuts against and fuses with the lateral continuation of the pons and then, bending backward, enters the overhanging cerebellum as the **inferior cerebellar peduncle.** This strand, also known as the **restiform body** (corpus restiforme), is seemingly the direct prolongation of the gracile and cuneate funiculi. Such, however, is not the case, since the fibres passing from these tracts to the cerebellum by way of the restiform body are the axones of the gracile and cuneate nuclei and, therefore, new links in the chain of conduction.

The inferior cerebellar peduncle is the most direct path by which the cerebellum is connected with the medulla and the spinal cord. In addition to the tracts originating in the cord and destined for the cerebellum (the direct cerebellar and possibly part of Gowers' tract), it comprises probably fibres passing in both directions; that is, from the cells within the medulla to the cerebellum, and from the cerebellar cells to the medulla. A more detailed account of these components will be given in connection with the structure of the medulla (page 1072). Upon close inspection of the surface of the medulla, the direct cerebellar tract is seen as an obliquely coursing band that at the lower level of the olive leaves the lateral area and gradually passes backward, over the upper and outer end of the Rolandic tubercle, to join the restiform body, within which it continues its journey to the cerebellum. The *anterior superficial arcuate fibres* also enter the restiform body, after sweeping around the inferior pole of the olive, or crossing its surface, and the upper part of the funiculus of Rolando. Additional contributions, the *posterior superficial arcuate fibres*, proceed to the restiform body from the gracile and cuneate nuclei of the same side. Just before bending backward to enter the cerebellum, the restiform body is crossed by a variable number of superficial strands, the **striæ acusticæ,** that may be traced from the floor of the fourth ventricle and around the inferior peduncle to the cochlear nucleus.

INTERNAL STRUCTURE OF THE MEDULLA OBLONGATA.

As already pointed out, the correspondence between the spinal cord and the medulla is only superficial, sections across the medulla revealing the presence of considerable masses of gray matter and important tracts of nerve-fibres not represented

FIG. 919.

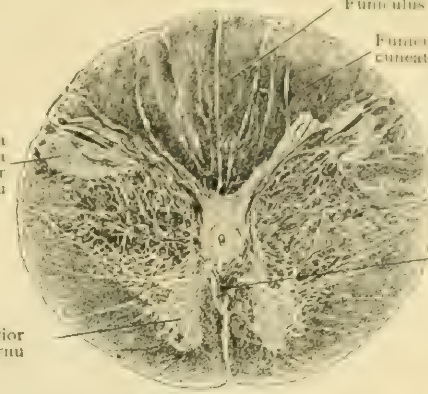


Ventral (*A*) and dorsal (*B*) aspects of brain stem, showing levels of sections which follow.

in the cord, as well as the rearrangement, modification or disappearance of spinal tracts which are prolonged into the bulb. In consequence, the medulla, even at its lower end, presents new features, and towards its upper limit varies so greatly from the cord that but slight resemblance to the latter is retained. The characteristic features displayed by transverse sections of the medulla at different levels depend upon the changes induced by four chief factors:—(1) the decussation of the pyramids, (2) the appearance of the dorsal nuclei, (3) the production of the formatio reticularis, and (4) the opening out of the fourth ventricle.

The effects of the decussation of the pyramidal tracts, assuming for convenience that the latter pass from below upward, are conspicuous when followed in consecutive transverse sections from the spino-bulbar junction cerebralward. The first suggestion of the decussation appears (Fig. 920) as strands of nerve-fibres, that pass from the field of the lateral pyramidal tract in the lateral column obliquely through the adjacent anterior horn of gray matter and across the bottom of the anterior median fissure to gain the opposite anterior column. At a slightly higher level, where the decussation is fully established (Fig. 921), the large strands of obliquely sectioned fibres are seen cutting through the gray matter, partly filling the median fissure, and collecting on either side of the latter as the large ventral bundles which thence upward constitute the prominent pyramidal fields. In consequence of the greater space required by the pyramids, the isolated anterior horns of the gray matter, cut off by the crossing strands, and the adjacent anterior ground-bundle are displaced laterally and at first lie to the outer side of the decussated fibres. Later, the ground-bundle assumes a position behind the pyramid and eventually becomes continuous with the posterior longitudinal fasciculus (page 1116). The detached anterior cornu of the gray matter is pushed outward and backward and gradually becomes broken up by and interspersed among the fibres of the formatio reticularis.

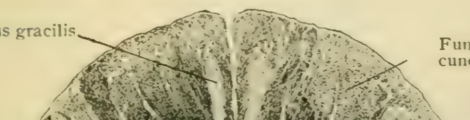
FIG. 920.



Transverse section of medulla at level A, Fig. 919; beginning of pyramidal decussation. Weigert-Pal staining. × 5½. Preparation made by Professor Spiller.

The Posterior Nuclei and the Arcuate Fibres.—The robust tracts of white matter (nerve-fibres) prolonged into the gracile and cuneate funiculi from the tracts of Goll and of Burdach become invaded by new masses of gray matter, the nucleus gracilis and cuneatus. The **gracile nucleus**, the first encountered, begins as a narrow area of gray matter within the corresponding strand, on a level with the pyramidal decussation (Fig. 921). It rapidly increases in bulk, until it not only invades the entire funiculus gracilis, but also joins the gray matter surrounding the central canal. The superficial stratum of spinal fibres gradually diminishes as more and more of its components end around the cells of the gracile nucleus, until, finally, all are interrupted. Meanwhile the **cuneate nucleus** appears within the funiculus cuneatus as a dorsally directed club-shaped mass of gray matter (Fig. 922) which soon becomes a prominent mottled area, sharply defined by the overlying stratum of Burdach fibres. The cuneate nucleus extends to a higher level than the nucleus

FIG. 921.

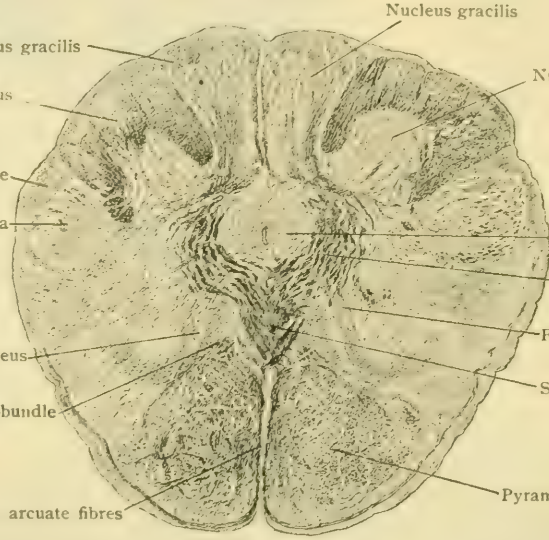


Transverse section of medulla at level B, Fig. 919; pyramidal decussation well established; posterior cornua are displaced laterally by posterior columns. × 5½. Preparation by Professor Spiller.

gracilis and, even after the disappearance of the latter, continues as a striking collection of gray matter beneath the dorsal surface of the medulla, from which it is separated by the posterior superficial arcuate fibres. Within the upper part of the fasciculus cuneatus the gray matter becomes subdivided into two masses (Fig. 924), the more superficial and continuous of which is called the *nucleus cuneatus externus*, and the deeper and more broken one, the *nucleus cuneatus internus.*

Owing to the increased bulk of the fasciculi of the posterior area occasioned by the appearance and expansion of the contained nuclei, the dorsal horns of the gray matter are displaced laterally and forward, so that they come to lie on a level with the central canal. Meanwhile the posterior cornua themselves, especially the capping substantia gelatinosa, materially gain in bulk and now appear as two club-shaped masses of gray matter that cause the dorso-lateral projections of the Rolandic tubercles seen on the

FIG. 922.



Transverse section of medulla at level C, Fig. 919, showing sensory decussation, posterior nuclei and pyramidal tracts. × 5¾. Preparation by Professor Spiller.

surface. Beneath the latter and closely overlying the outer border of the extensive area of the substantia gelatinosa, a crescentic tract of the longitudinally coursing nerve-fibres marks the position of the descending root of the trigeminal nerve (Fig. 922).

The chief purpose of the gracile and cuneate nuclei being the reception of the long sensory tracts continued from the cord and the distribution of impulses so received to the cerebellum and to the higher centres, it is evident that new paths of the second order must arise within these nuclei. About on a level with the upper limit of the pyramidal or motor decussation, fibres emerge from the gracile and cuneate nuclei, sweep forward and inward in bold curves and cross the median raphe to the opposite side of the medulla, immediately behind the pyramids (Fig. 922). They then turn sharply upward and form the beginning of the important sensory pathway known as the **median fillet** (**lemniscus medialis**) that connects the medullary nuclei with the higher centres, as the superior corpora quadrigemina and the optic thalamus. The first fibres that emerge in this manner from the gracile and cuneate nuclei constitute a fairly well defined strand to which the name **sensory decussation** or **decussation of the fillet** is given. It must not be supposed, however, that with this decussation the crossing ceases, for, quite the contrary, it is only the beginning of an extended series of sensory fibres that pass across the raphe at various levels throughout the brain-stem. As many longitudinally coursing fibres are encountered by those sweeping from side to side, an interweaving of vertical and horizontal fibres occurs, which results in the production of the characteristic **formatio reticularis** that constitutes a large part of the medulla, as well as of the dorsal or tegmental portions

of the pons and cerebral crura. A feeble expression of a somewhat similar structure is seen in the reticular formation within the lateral column of the spinal cord.

The Arcuate Fibres.—These originate as the axones of the cells of the gracile and cuneate nuclei and include three sets. The first, the **deep arcuate fibres**, turn sharply brainward after crossing the raphe and constitute the chief constituents of the mesial fillet. The second set, the **anterior superficial arcuate fibres**, also cross the mid-line, but these, instead of turning upward, pass forward, enter through the pyramid or along its median aspect, and, gaining the surface, sweep over the pyramid and olivary eminence and thence proceed backward to the restiform body and on to the cerebellum. An oval collection of small fusiform nerve-cells, the **arcuate nucleus** (**nucleus arcuatus**) lies in the path of these fibres, at first on the ventral surface of the pyramid and then along the median fissure. Whilst some additional arcuate fibres arise from the cells of the nucleus, the majority sweep by without interruption. The third set, the **posterior superficial arcuate fibres**, proceed from the cells of the gracile and cuneate nuclei of the same side and pass beneath the ventricular floor to the adjacent restiform body and thence to the cerebellum.

FIG. 923.

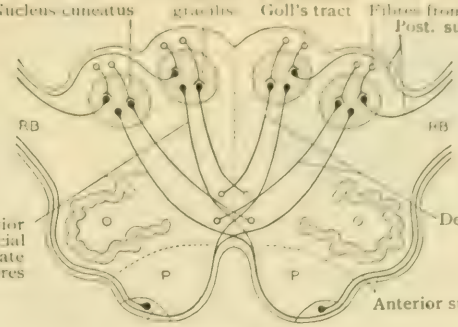
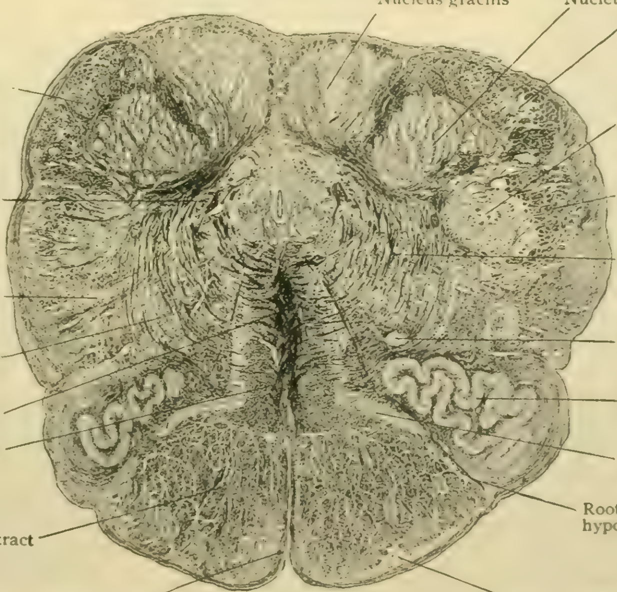


Diagram illustrating source and path of arcuate fibres; RB, restiform body; P, pyramidal tract; O, inferior olivary nucleus.

FIG. 924.



Transverse section of medulla at level D, Fig. 919, showing posterior nuclei, inferior olivary nuclei, formatio reticularis and dorsal displacement of central canal. × 5¼. Preparation by Professor Spiller.

The Olivary Nuclei.—These include, in each half of the medulla, three masses of gray matter—the inferior olivary nucleus and the two accessory olivary nuclei. Beneath the prominent olivary eminence lies a corrugated sack-like lamina of gray

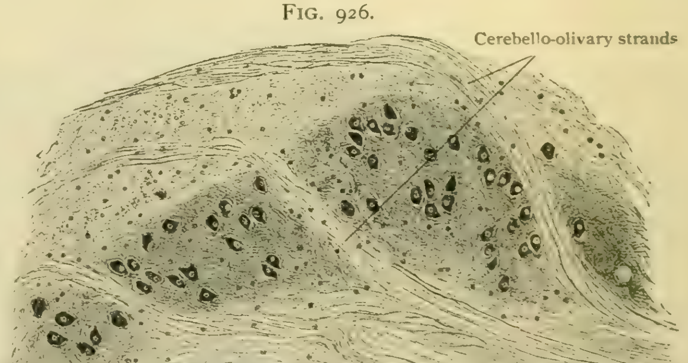
matter, the **inferior olivary nucleus** (**nucleus olivaris inferior**), which in favorable transverse sections appears as a conspicuous sinuous C-like figure. The nucleus resembles a greatly crumpled bag, of which the closed end lies beneath the corresponding superficial protuberance and the mouth, or *hilum*, looks mesially and somewhat dorsally. When reconstructed and viewed from the side (Fig. 925), the plications of the lateral and dorso-lateral surfaces display a general antero-lateral disposition. On the ventral surface the grooves radiate from the ventral border of the hilum (Sabin). The greatest length of the inferior olivary nucleus is from 12–15 mm., its transverse diameter is about 6 mm., and its vertical one about one millimeter less. The somewhat compressed hilum measures sagittally from 8–9 mm. The plicated lamina of gray matter composing the wall of the sac is from .2–.3 mm. in thickness and contains numerous small irregularly spherical nerve-cells, each provided with a variable number of dendrites and an axone, embedded within a compact feltwork of neuroglia fibres. The interior of the gray sac is filled with white matter consisting of nerve-fibres that, for the most part, stream through the hilum and thus constitute the *olivary peduncle*. These strands, known as the **cerebello-olivary fibres**, connect the cerebellar cortex with the inferior olivary nucleus and probably pass in both directions. Many fibres, the axones of the olivary neurones, issue from the hilum on the one side, cross the mid-line and, sweeping through the opposite olivary nucleus either by way of the hilum or directly traversing the gray lamina, continue their course to the restiform body and thence to the cerebellum. Other fibres originate in the cells of the cerebellar cortex and proceed in the opposite direction along the same pathway to end in relation with the cells of the inferior olivary nucleus. The further links in the chain of conduction are uncertain; according to Kölliker it is probable that from some of the olivary cells, fibres pass downward into the antero-lateral ground-bundle of the cord.

FIG. 925.

Dorso-lateral aspect of inferior olivary nucleus as reconstructed by Dr. Florence R. Sabin. × 5.

The **accessory olivary nuclei** are two irregular plate-like masses of gray matter that lie respectively mesially and dorsally to the chief olive. The first of these, the *mesial accessory olivary nucleus* (**nucleus olivaris accessorius mesialis**) is a sagittally placed lamina, from 10–11 mm. in length, which lies between the tract of the fillet and the root-fibres of the hypoglossal nerve. It extends below the inferior olive and, therefore, is encountered in transverse sections at a lower level—immediately above the pyramidal decussation—than the main nucleus. According to the reconstructions of Sabin, the nucleus comprises three dorso-ventral columns of cells, of

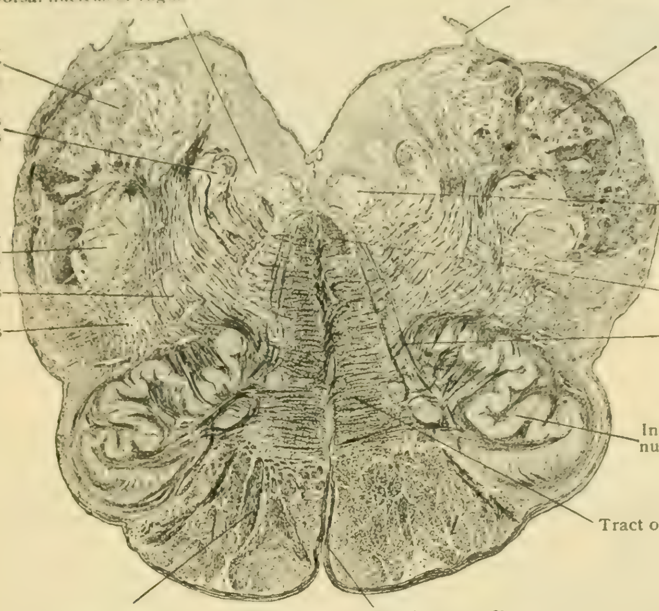
FIG. 926.



Section of inferior olivary nucleus, showing plicated sheet of gray substance traversed by strands of cerebello-olivary fibres. × 100.

which the lower and middle are continuous and the upper is unconnected, and four small isolated masses of gray matter along the dorsal border of the nucleus. The inferior or spinal end of the nucleus is thickened and bent outward, so that its plane is oblique and parallel with the ventral surface of the chief olive. Higher, when the latter is well established, the mesial accessory nucleus is represented by a narrow broken tract, that corresponds more closely with the sagittal plane. In this situation the nucleus lies between the fillet and the inner end of the chief olive and across

FIG. 927.



Transverse section of medulla at level E, Fig. 919; central canal has opened into fourth ventricle; restiform body appearing. × 5. Preparation by Professor Spiller.

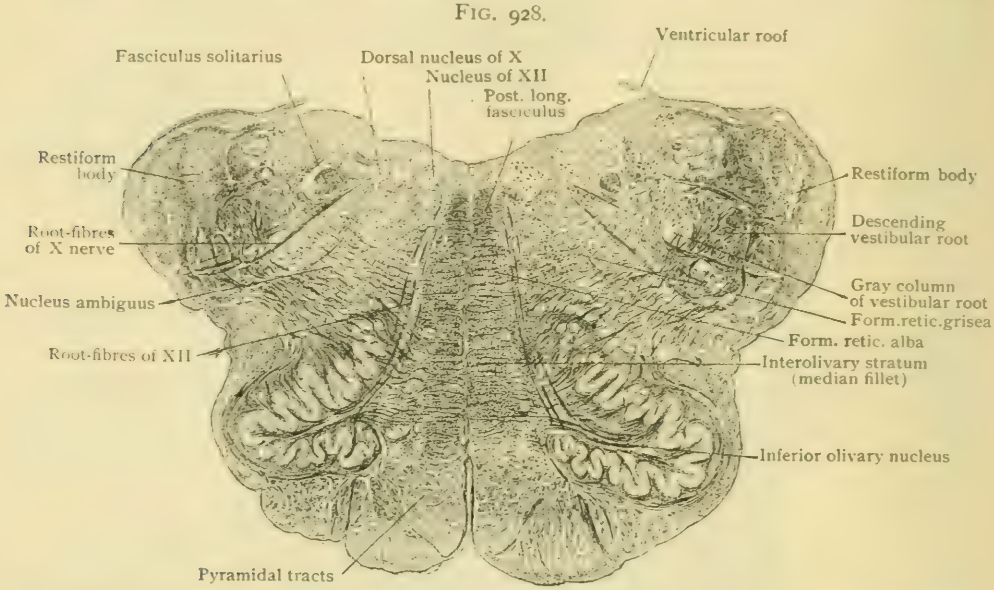
its hilum. The *dorsal accessory olivary nucleus* (**nucleus olivaris accessorius dorsalis**) is less extensive than the median, measuring about 9 mm. in length, and lies close to and behind the posterior lip of the hilum of the inferior olive.

The Central Gray Matter.—As pointed out, within the closed part of the medulla the central canal and the surrounding gray matter are gradually displaced dorsally in consequence of the increasing space required by the pyramid, the fillet tract and the posterior longitudinal fasciculus, three paired tracts of longitudinally coursing fibres that lie close to the median raphe and enlarge as they are followed upward. When the central canal opens out into the fourth ventricle, the surrounding gray matter is correspondingly spread out and forms the lining of the ventricular floor. Within this gray sheet and near the mid-line, on each side, is seen the group of cells constituting the hypoglossal nucleus from which the fibres of the twelfth cranial nerve arise. These strands take a direct ventro-lateral course through the medulla and emerge on the surface in the groove between the pyramid and olivary eminence. Slightly more lateral, and to the outer side of the hypoglossal nucleus, another group of cells marks the position of the elongated *vago-glosso-pharyngeal nucleus*, partly sensory and partly motor, belonging to the tenth and ninth cranial nerves. The fibres of the vagus traverse the medulla laterally and meet the surface at the junction of the lateral and posterior areas. In this way the diverging fibres of the tenth and twelfth nerves subdivide each half of the medulla into three triangular areas—a mesial, a lateral and a posterior (Flechsig).

Viewed in transverse sections through the upper third of the medulla, the **posterior area**—the space between the vagus fibres and the dorsal surface of the medulla—is seen to contain a number of important fibre-tracts. (1) The *restiform body* appears

as a large irregularly crescentic tract of transversely cut fibres that occupies the greater part of the periphery. (2) The *descending root of the vestibular nerve* is seen to the inner side of the dorso-mesial border of the restiform body as a field of loosely grouped bundles of cross-sectioned nerve-fibres. (3) The *fasciculus solitarius*, or

FIG. 928.

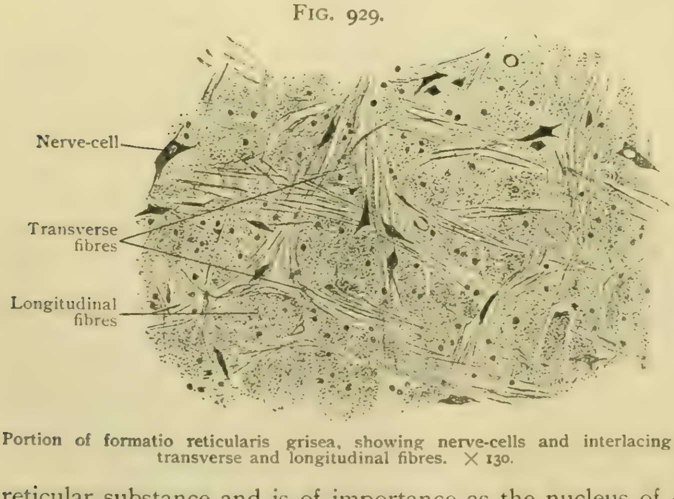


Transverse section of medulla at level F, Fig. 919; ventricular floor is wide; restiform body well established; descending root of vestibular nerve is seen. × 5. Preparation by Professor Spiller.

descending root of the vagus and glosso-pharyngeal nerves, shows as a conspicuous transversely cut bundle which lies ventro-mesially to the vestibular root. (4) The *descending root of the trigeminal nerve* is easily identified as a superficial crescentic field that on its mesial aspect encloses the remains of the substantia gelatinosa Rolandi.

The **lateral area,** between the diverging vagus and hypoglossal root-fibres, is chiefly occupied, in addition to (1) the *inferior olivary* and (2) *dorsal accessory olivary nucleus*, by the feltwork of fibres producing the reticular formation. In contrast to that within the anterior area, the reticulum within the lateral area contains a considerable amount of diffuse gray matter between its fibres, and, hence, is known as (3) the *formatio reticularis grisea.* Accessions to the irregularly distributed nerve-cells occur as two more definite collections; one of these, (4) the *nucleus ambiguus*, consists of an inconspicuous group of large cells lying about the middle of the gray reticular substance and is of importance as the nucleus of origin of at least part of the motor fibres of the vagus nerve. The other (5), the *nucleus lateralis*, includes an uncertain aggregation of medium sized cells, situated near the periphery and ventral

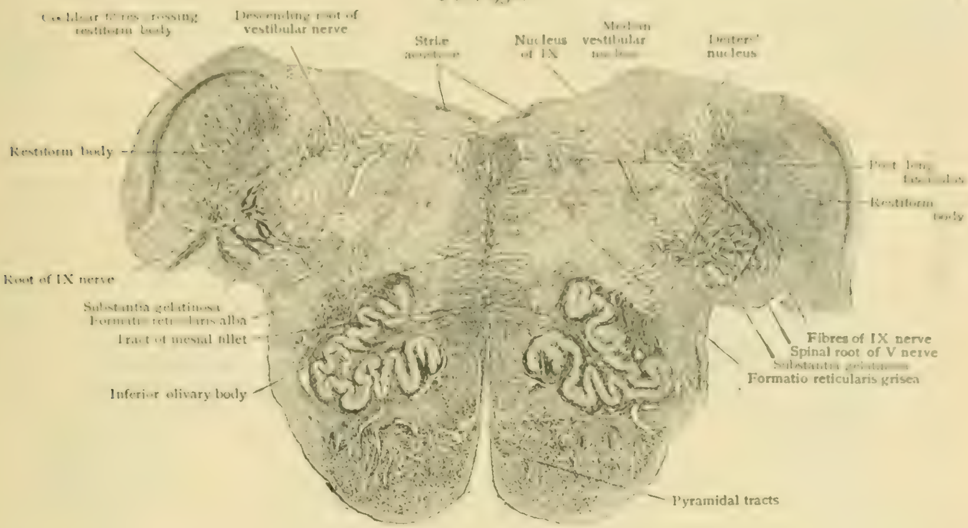
FIG. 929.



Portion of formatio reticularis grisea, showing nerve-cells and interlacing transverse and longitudinal fibres. × 130.

from the trigeminal root. A separate group of somewhat larger cells, nearer the ventral border of the trifacial root, has been designated the *nucleus lateralis dorsalis*, and by Kolliker regarded as belonging to the origin of the spinal accessory nerve.

FIG. 930.

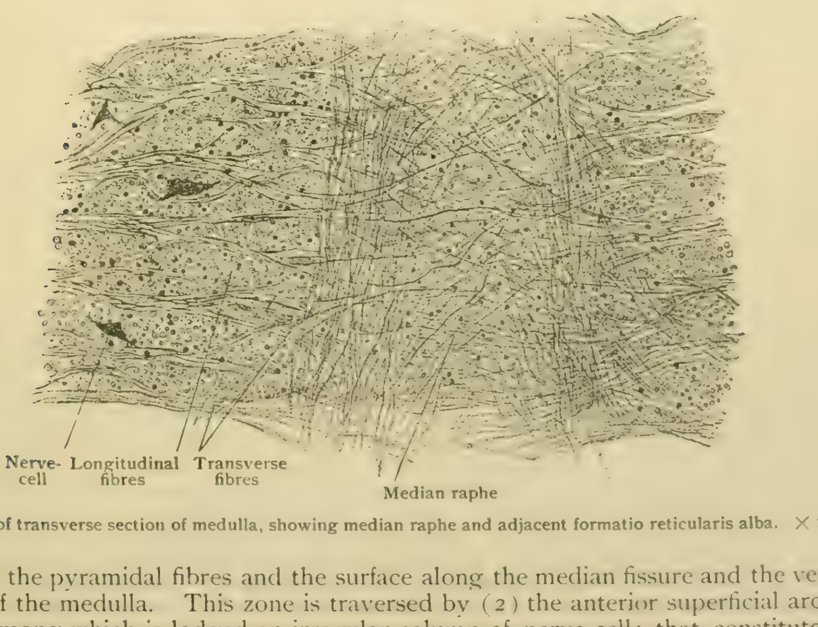


Transverse section of medulla at level G, Fig. 919; ventral part is narrower, whilst dorsal part is expanded owing to increased size of restiform bodies. × 4. Preparation by Professor Spiller.

In a general way the cells of these nuclei (ambiguus and lateralis) of the substantia grisea may be regarded as the analogues of the lateral horn-cells of the cord, just as those of the hypoglossal nucleus resemble the anterior root-cells of the spinal nerves.

The **anterior area**, between the mid-line and the hypoglossal root-fibres, is occupied ventrally by (1) the *pyramidal tract*, which appropriates the entire width of the field with the exception of a very narrow peripheral zone that intervenes

FIG. 931.



Portion of transverse section of medulla, showing median raphe and adjacent formatio reticularis alba. × 130.

between the pyramidal fibres and the surface along the median fissure and the ventral aspect of the medulla. This zone is traversed by (2) the anterior superficial arcuate fibres, among which is lodged an irregular column of nerve-cells that constitute (3)

the *arcuate nucleus*. The latter lies at first chiefly on the ventral and, higher, on the mesial aspect of the pyramidal tract. The cells of this nucleus, small and fusiform, are the origin of not a few of the superficial arcuate fibres, although those from the dorsal nuclei continue their course over the nucleus without interruption. At the upper end of the medulla, the cells of the arcuate nucleus increase in number and mingle with those of the nucleus of the raphe and the pontile nucleus.

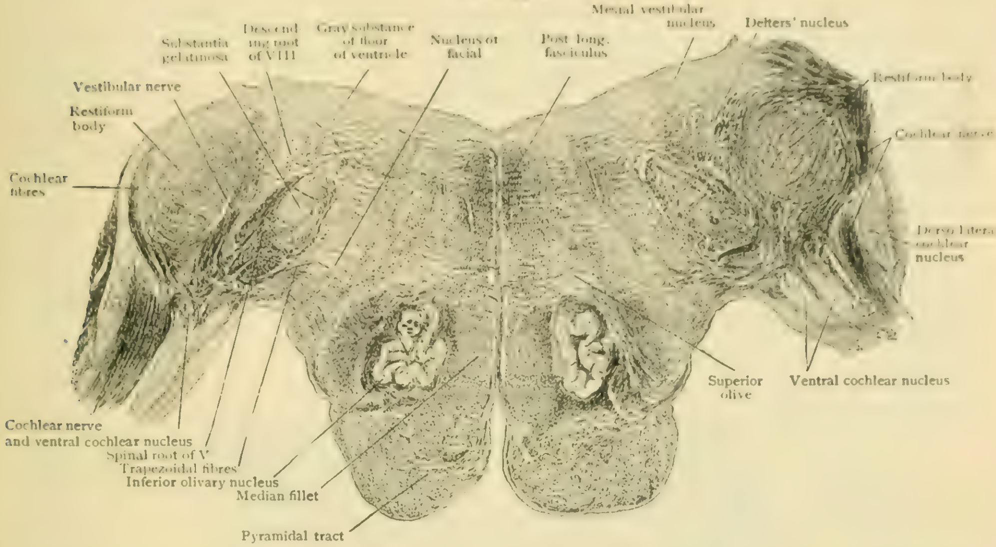
Dorsal to the pyramid and immediately next the mid-line lies (4) the compact *tract of the median fillet*, composed of longitudinal fibres that are the upward continuation of the deep arcuate fibres, which, from the sensory decussation to the upper limit of the cuneate nucleus, bend sharply brainward after crossing the mid-line. The fillet-tracts are also known as the *interolivary stratum*, as they constitute a compact and laterally compressed field between the inferior olivary nuclei. Lateral to the fillet, between the latter and the hypoglossal fibres, lies (5) the *mesial accessory olivary nucleus*. (6) The *posterior longitudinal fasciculus* appears in cross-section as a compact oval or laterally flattened strand, which lies next the raphe and immediately beneath the gray matter covering the floor of the fourth ventricle. This important path will be later described (page 1116). The remaining space of the anterior compartment, between the pyramid and the ventricular gray matter, is occupied by the *formatio reticularis alba*, so designated in distinction to the formatio grisea on account of its meagre number of nerve-cells, since, with the exception of those scattered in the immediate vicinity of the mid-line (**nucleus raphe**), few cells are present.

The Formatio Reticularis.—Repeated mention has been made of the reticular formation produced by the interweaving of the horizontal and vertical fibres. Whilst particularly conspicuous within the medulla at the levels occupied by the gracile, cuneate and inferior olivary nuclei, on account of the prominence of the arcuate and cerebello-olivary fibres, the formatio reticularis does not end with the disappearance of these nuclei and fibres, but is prolonged upward, although less marked, by transversely coursing fibres derived from the reception-nuclei of various cranial nerves—the vagus, glosso-pharyngeal, auditory, facial, and trigeminal—from whose neurones axones of the second order arise that sweep across the mid-line to join chiefly the fillet tract or to end, perhaps, about nerve-cells of other nuclei. In this manner the formatio reticularis finds representation within the dorsal or tegmental areas of the pons and the cerebral crura. The longitudinal fibres within the formatio reticularis grisea are derived from many sources. Some are the continuation of Gowers' tract; some belong to the long strands concerned in establishing reflex paths connecting the corpora quadrigemina, nucleus rubrum, vestibular and olivary nuclei with the spinal cord; some are the axones of tegmental neurones and pursue shorter courses, both descending and ascending, as association fibres linking together different levels of the brain-stem; while still others are the prolongations of the spino-thalamic and other long tracts of the antero-lateral ground-bundle of the cord. The longitudinal fibres of the formatio alba are chiefly the components of the mesial fillet and of the posterior longitudinal fasciculus with, possibly, the addition of short association fibres proceeding from the nerve-cells that are found within the anterior area.

The details of a transverse section passing just beneath the lower border of the pons (Fig. 932) vary considerably from those of the level shown in Fig. 930. The ventral half of the medulla has lost in width in consequence of the disappearance of the superficial olivary eminence, the inferior olive being at this level represented by only a few irregular plications. The pyramids, likewise, are narrower, and separated by the broadened anterior median fissure. The mesial fillet and the posterior longitudinal fasciculus are now widely separated by the intervening nucleus centralis inferior that appears between them along the raphe. The nuclei of the hypoglossal and glosso-pharyngeal nerves are no longer seen, but instead, along the floor of the ventricle underlying the area acustica, appears a large triangular mass of gray matter, the *mesial vestibular nucleus*. External to the latter the *lateral* or *Deiters' nucleus* and the descending or spinal vestibular root lie close to the restiform body, which in transverse section presents a bean-shaped outline. Between the restiform body and the descending trigeminal root, the fibres of the mesial or *vestibular part* of the auditory nerve pass backward to gain the vestibular nuclei. The outer surface of the restiform body is closely related to a considerable

tract of gray matter that collectively constitutes the reception-nucleus of the cochlear division of the auditory nerve. This ganglion is subdivided into a superior and an inferior portion, these being the *dorsal cochlear nucleus* and the *ventral cochlear nucleus* respectively. They both receive the fibres of the cochlear or lateral division of the auditory nerve. The ventral cochlear nucleus is the starting point of a tract of transverse fibres, that pass horizontally inward, many traversing the fillet and crossing the raphe, and intermingle with those from the opposite side. They thus form a broad strand, the *corpus trapezoides*, that within the pons occupies the lower limit of the tegmental region, which it separates from the ventral. In Fig. 932

FIG. 932.



Transverse section of medulla at level H, Fig. 919; pyramids are small and inferior olivary nuclei are disappearing; roots of auditory nerve are entering in relation to restiform bodies. × 4. Preparation by Professor Spiller.

only the beginning of this tract is visible, but slightly higher, in the pons (Fig. 933), the trapezoidal fibres are shown in force. Strands of fibres from the cochlear nuclei arch over the restiform body and proceed beneath the ventricular floor to the mid-groove; these mark the course of the *striæ acusticæ* seen crossing the ventricle. Ventro-mesial to the spinal root of the trigeminus and the associated Rolandic substance the *nucleus of the facial nerve* appears as an irregularly oval and somewhat broken group of large stellate cells, from which the strands of root-fibres pass dorso-medially.

THE PONS VAROLII.

Viewed from in front, the pons appears as a quadrilateral prominence on the ventral aspect of the brain, interposed between the medulla oblongata below, the cerebral peduncles above, and the cerebellar hemispheres at the sides. Its lower and upper limits are well defined by grooves that separate the corresponding borders from the adjacent divisions of the brain-stem, and between these boundaries the pons measures from 25–28 mm. in the mid-line. Laterally, however, its limits are unmarked, as here the mass of the pons narrows and is directly continued on each side as a robust arm which sweeps downward and backward into the cerebellum as the **middle cerebellar peduncle.** The fibres of the trigeminal nerves, which are attached near its upper and lateral margins, are taken as the conventional lateral limits of the pons, the transverse diameter measured between these points being about 30 mm.

The **ventral surface** of the pons, strongly convex transversely and less so in the opposite direction, lies behind the basilar process of the occipital bone and the dorsum sellæ. It is marked by a shallow median groove (**sulcus basilaris**), which broadens as it ascends and lodges the basilar artery and is bounded on each side by a slight longitudinal elevation. Where the latter meets the medulla, the pyramid is seen to plunge into the pons beneath its transversely striated surface. The longitudinal

ridges are produced by the underlying pyramidal tracts in their journey through the pons from the cerebral peduncles to the medulla. The transverse striation indicates the general course of the superficial fibres towards the cerebellum.

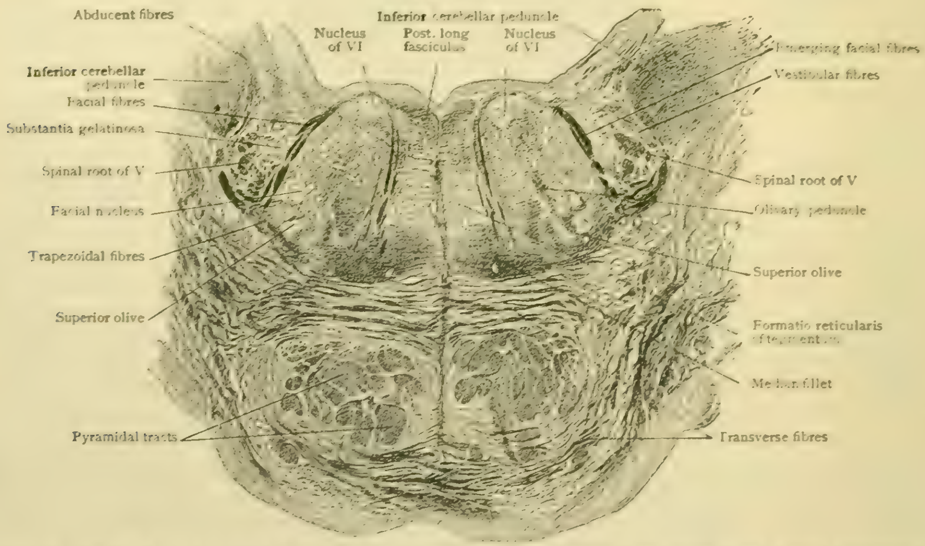
The **lateral surface**, continued from the ventral without interruption, above is rounded and sloping and separated from the cerebral peduncles by a distinct furrow. Below, it passes insensibly into the middle cerebellar peduncle, into which the lower and lateral part of the pons is prolonged. Whilst the superficial striation in a general way follows the contour of the pons, a broad band (**fasciculus obliquus pontis**) from the upper part of the ventral surface sweeps obliquely backward and downward and overlies the more horizontally directed middle and lower fibres.

The free portion of the **dorsal surface** of the pons contributes the upper half of the floor of the fourth ventricle and is, therefore, not visible until the roof of that cavity is removed. Above the middle peduncle, the sides of the pons are blended with the overlying *superior cerebellar peduncles*, which, in conjunction with the intervening *superior medullary velum*, complete dorsally the ring of tissue surrounding the narrowed superior end of the fourth ventricle.

INTERNAL STRUCTURE OF THE PONS VAROLII.

Viewed in transverse sections the pons is seen to include two clearly defined areas, the ventral and the dorsal (Fig. 933). The **ventral part** (**pars basilaris**) presents a characteristic picture in which the large pyramidal tracts are covered in

FIG. 933.



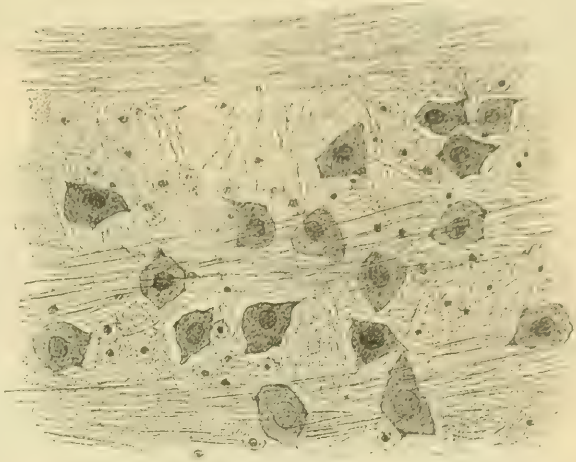
Transverse section of pons at level I, Fig. 919, showing general subdivision into ventral and dorsal (tegmental) areas and nuclei of sixth and seventh nerves. × 3.

and excluded from the surface by a conspicuous layer of superficial transverse fibres (**stratum superficiale pontis**), that laterally sweep backward into the cerebellar peduncle and are traversed by the root-fibres of the seventh and eighth nerves. The pyramids no longer appear as compact fields, but are broken up into smaller bundles by the transverse strands of ponto-cerebellar fibres. This subdivision becomes more marked at higher levels of the pons (Fig. 936), in which the interweaving of the longitudinal and transverse bundles produces a coarse feltwork (**stratum complexum**). At the upper border of the pons, the scattered pyramidal bundles become once more collected into two compact strands, which are continued into the central part of the crusta of the cerebral peduncle. The dorsal limit of the ventral field is occupied by a well marked deeper layer of transverse fibres (**stratum profundum pontis**). A considerable amount of gray matter, collectively known as the **pontile nucleus**

(**nucleus pontis**) is distributed within the interstices between the bundles of nerve-fibres. The cells of this nucleus, small in size and stellate in form, are closely related to the ponto-cerebellar fibres of the same and of the opposite side, many constituting stations of interruption in the cortico-cerebellar paths.

The **dorsal** or **tegmental part** of the pons (**pars dorsalis pontis**) resembles to a considerable extent in its general structure the formatio reticularis grisea of the medulla, consisting for the most part of a reticulum of transverse and longitudinal fibres, interspersed with nerve-cells, on each side of the median raphe. The appearance of certain new masses of gray matter and of nerve-fibres, together with changes in the position of the fillet, produce details that vary with the level of the section. When this passes above the lower margin of the pons (Fig. 933), two diverging and obliquely cut strands of fibres, coursing from the ventricular floor towards the ventral aspect, mark the root-fibres of the sixth and seventh cranial nerves and divide the dorsal region, on each side, into three areas. The **middle area,** between the abducent fibres mesially and the facial fibres laterally, contains three important collections of nerve-cells. One of these, the **nucleus of the sixth nerve,** lies close to the floor of the ventricle and beneath the rounded prominence of the eminentia teres, which it helps to produce, and gives origin to the root-fibres of the abducent nerve. These fibres take an obliquely ventral path, slightly bowed towards the raphe, and cut through not only the dorsal but also the ventral part of the pons to gain its lower border, along which they emerge a few millimeters from the mid-line. In favorable sections the nucleus of the sixth is seen separated from the floor of the fourth ventricle by the arching fibres of the facial nerve.

FIG. 934.



Portion of cross-section of pons, showing cells of pontine nucleus. × 300.

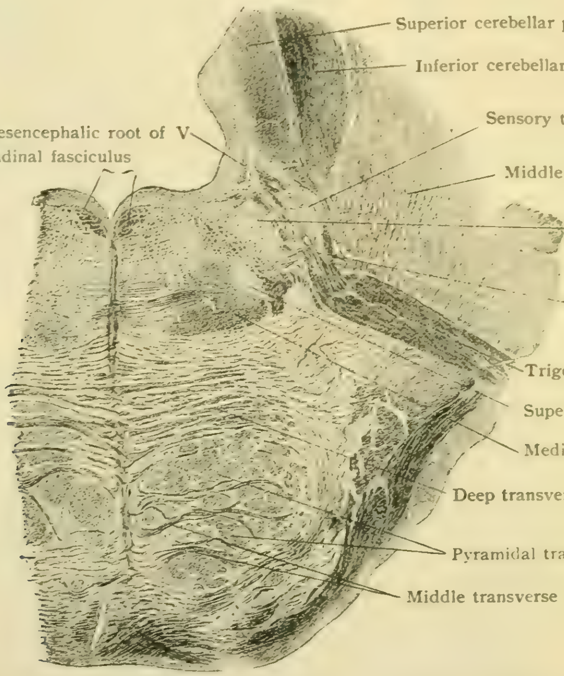
Another conspicuous nucleus of the middle area, the **superior olive** (**nucleus olivaris superior**), lies near the ventral limit of the tegmental area, partly lodged within an indentation on the dorsal surface of the conspicuous tract of transverse fibres, known as the **corpus trapezoideum**, that extends from the ventral cochlear nucleus medially and materially aids in defining the ventral boundary of the dorsal area. The superior olive (Fig. 933) is an irregularly spherical collection of nerve-cells, interposed in the path connecting the auditory nuclei with the cerebral cortex, and closely related with the tract of the lateral fillet (page 1082). In addition to contributing numerous fibres to the latter, the superior olive sends others to the abducent nucleus which are seen as delicate strands, the *peduncle of the superior olive*, that pass towards the nucleus of the sixth nerve and bring this centre into relation with auditory impulses. A small collection of nerve-cells between the fibres of the trapezoidal tract, ventro-medial to the superior olive, constitutes the *nucleus trapezoideum.* Close to the medial border of the superior olive a small oval bundle of longitudinal fibres, the *central tegmental fasciculus*, is sometimes seen. These fibres are probably derived from the olivary nucleus (Obersteiner).

The **facial nucleus,** a conspicuous but broken oval mass of gray matter (Fig. 933), includes several groups of large stellate cells that lie dorso-lateral to the superior olive and to the inner side of the emerging facial fibres. From the cells of this nucleus the loosely collected root-fibres of the facial nerve pass backward and inward to reach the floor of the fourth ventricle. Here they converge into

a compact strand that, as the ascending portion of the nerve, courses beneath the eminentia teres seen on the ventricular floor, close to the mid-line, until it bends outward and, arching around the abducent nucleus, continues ventrally as the emerging root-fibres.

The ventral part of the inner area and the adjoining part of the middle one are occupied by the field of the *mesial fillet* which, at the level under consideration, no longer has its longest axis directed dorso-ventrally, but approximately horizontal. The tract now appears as a modified oval, somewhat compressed from before backward, the thicker inner end of which reaches the raphe while the tapering outer end lies near the superior olive. The *posterior longitudinal fasciculus* is seen as a compact strand, immediately beneath the gray matter of the ventricular floor and at the side of the raphe. To the outer side of the emerging facial fibres, and therefore in

FIG. 935.



Transverse section of pons at level J, Fig. 919, showing root of trigeminal nerve with its nuclei. × 3. Preparation by Professor Spiller.

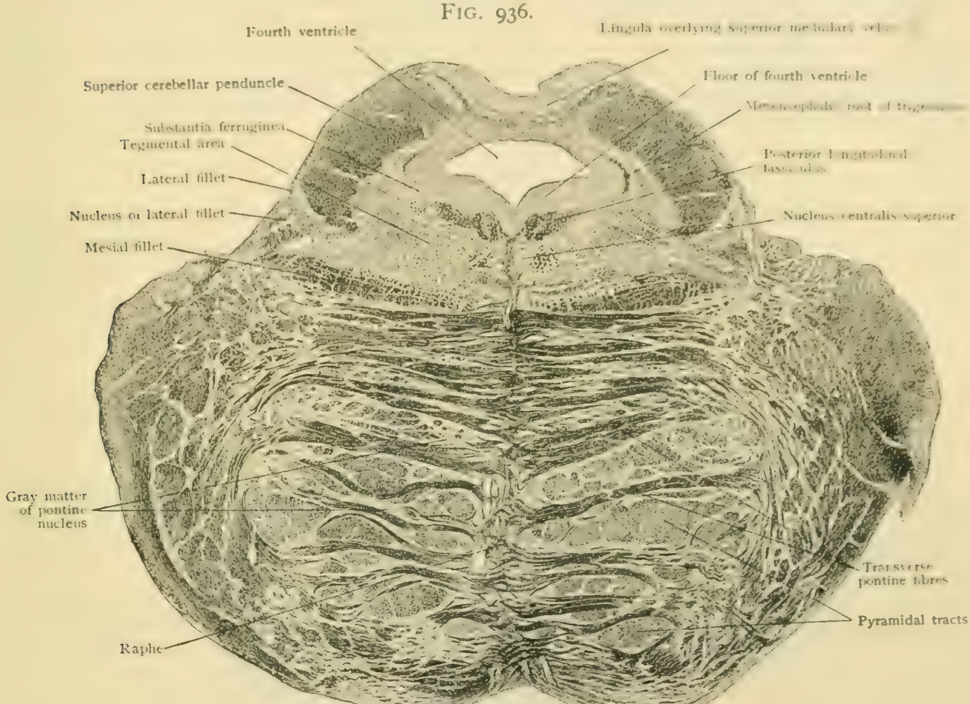
the lateral pontine area, appear the *substantia gelatinosa* and the associated *spinal root* of the trigeminal nerve. Just behind the latter the *descending vestibular root* lies close to the inner side of the restiform body. The collection of nerve-cells marking *Deiters' nucleus* is seen beneath the ventricular floor in close relation with the descending vestibular root.

Sections passing at the level of Fig. 935, and, therefore, about three millimeters above that of Fig. 933, show interesting details connected with the *nuclei* and *roots of the trigeminal nerve.* At this level the nuclei and roots of the sixth and seventh nerves are no longer seen. The *median fillet* appears on each side as a compressed oval, the long axis of which is horizontal and whose inner end almost touches the raphe. Just above the outer end of the fillet, the cerebral extremity of the superior olive is still visible, to which a few strands of transverse fibres—the last of the trapezoid body—pass. The lateral boundary of the ventral part of the pons is defined by a hugh tract of obliquely cut fibres that marks the entering *sensory root* of the trigeminal nerve. On following this tract dorsally it is seen to enter a large mass of gray matter, the *sensory nucleus* of the trigeminal nerve. This ganglion, composed of closely packed small multipolar cells, corresponds to an accumulation of the *substantia gelatinosa*, which, it will be remembered, is to be seen in all the preceding lower levels intimately related

to the *descending* or *spinal root* of the fifth nerve. A second and more compact ganglion, the *motor nucleus* of the trigeminus, lies to the inner side and slightly farther back. It contains large multipolar cells, extends to a somewhat higher level than the sensory nucleus, and is separated from the latter by a strand of fibres which arch over the motor nucleus and then pass mesially beneath the ventricular floor to the raphe, where they cross to the motor nucleus of the opposite side. These fibres are part of the crossed constituents of the motor trigeminal root. Additional components of the latter, the *descending* or *mesencephalic root*, are seen in the interval between the superior cerebellar peduncle and the lateral angle of the ventricle. The *motor root* itself is represented by several inconspicuous and broken strands of fibres that emerge from the motor nucleus and lie close to the inner side of the large sensory root.

Lateral to the sensory nucleus and root of the fifth, and therefore beyond the conventional limits of the pons, the section includes the three large fibre-tracts of the three cerebellar peduncles. The most anterior of these is the *middle peduncle* into which the corresponding ventral part of the pons is continued. The next and middle tract, joining the tegmentum to the

FIG. 936.



Transverse section of pons at level K, Fig. 919, showing fourth ventricle closed by superior cerebellar penduncles and superior medullary velum. × 3. Preparation by Professor Spiller.

outer side of the sensory trifacial nucleus, is the now obliquely cut *inferior peduncle* or *restiform body*. The third and dorsal tract is part of the *superior peduncle*, which being crescentic in cross-section, is here represented by its ventral edge. The three peduncles are thus intimately related as they pass into the central core of white matter of the cerebellum.

In sections passing at levels above the middle cerebellar peduncle (Fig. 936), the ventro-lateral surface of the pons is free and unattached and passes over the rounded dorso-lateral border onto the free posterior surface of the projecting part of the pons. Behind, the latter is blended with the robust arms, the *superior cerebellar peduncles*, that form the lateral walls of the upper part of the narrowing fourth ventricle. This latter space is roofed in by the *superior medullary velum* which stretches across the ventricle between the superior peduncles and on its upper surface supports the thin lamina of cerebellar cortical gray matter belonging to the lingula of the superior worm.

The floor of the ventricle is grooved in the mid-line by a furrow bounded on each side by an elevation—the upward prolongation of the *eminentia teres*. The depression at the lateral angle of the ventricular floor is the upper part of the *fovea superior*.

Beneath the latter are grouped the deeply pigmented nerve-cells of the *substantia ferruginea* that, seen through the intervening layer of tissue, confer the characteristic bluish tint of the

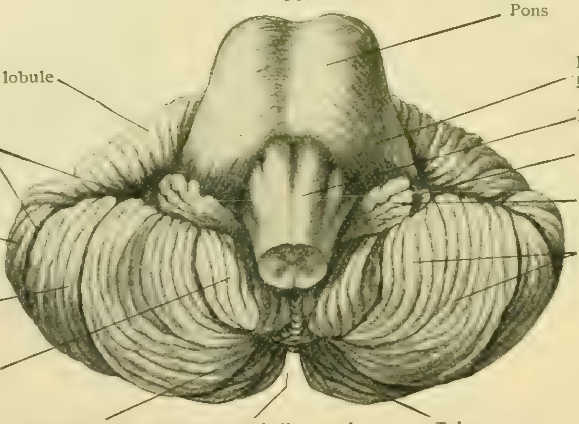
locus cæruleus to this part of the ventricle (page 1098). Mesial to these cells the *posterior longitudinal fasciculus* shows, in transverse section, as a triangular field close to and on each side of the raphe.

The most conspicuous feature of the dorsal part of the section is the comma-shaped fibre-tract of the **superior cerebellar peduncle** (**brachium conjunctivum**). The thicker part of the tract lies dorsally and its thinner edge cuts into the lateral part of the posterior area of the pons about half way between its dorsal and ventral boundaries. Between the cerebellar tract and the lateral angle of the ventricle, a slender crescentic strand of transversely cut fibres marks the *descending motor* or *mesencephalic root* of the trigeminal nerve. The tract of the *median fillet* no longer touches the raphe, but lies as a compressed and horizontally elongated oval along the ventral border of the dorsal field. The three-cornered area included between the outer end of the mesial fillet, the cerebellar arm and the surface, contains a curved triangular tract that sweeps backward and insinuates its pointed dorsal extremity along the outer side of the cerebellar strand. This tract is the **lateral fillet** (**lemniscus lateralis**), an important part of the pathway by which auditory impulses are carried from the reception-nuclei of the eighth nerve to the inferior corpora quadrigemina, the internal geniculate body and the cerebral cortex. A collection of small nerve-cells, embedded within the outer angle of this tract, gives rise to a number of its component fibres and is, therefore, known as the *nucleus of the lateral fillet* (**nucleus lemniscus lateralis**). An additional group, between the lateral fillet and the cerebellar tract, constitutes the *nucleus tegmenti lateralis* (Kölliker). The remainder of the tegmental area is occupied by the formatio reticularis.

THE CEREBELLUM.

The cerebellum—the "little brain," in contrast to the cerebrum or "great brain"—is placed in the posterior fossa of the skull and beneath the tent-like shelf of dura, the tentorium, which separates it from the overlying posterior part of the

FIG. 937.



Cerebellum viewed from in front and below; pons and medulla occupy greater part of vallecula and mask worm.

cerebral hemispheres. It lies behind the pons and medulla and the fourth ventricle, with the roof of which space it is intimately related. By means of its three peduncles —inferior, middle and superior—the cerebellum is connected with the medulla, the pons and the mid-brain respectively.

The general form of the cerebellum is that of an ellipsoid, compressed from above downward and constricted, save on the dorsal aspect, by a median groove of varying proportions. Its greatest dimension is the transverse diameter, about 10 cm. (4 in.); its least is the vertical (3 cm.), while in the sagittal direction the cerebellum measures about 4 cm. in the mid-line and about 6 cm. at the side. The cerebellum weighs about 140 gm. (5 oz.) and constitutes approximately one-tenth of the entire brain-weight.

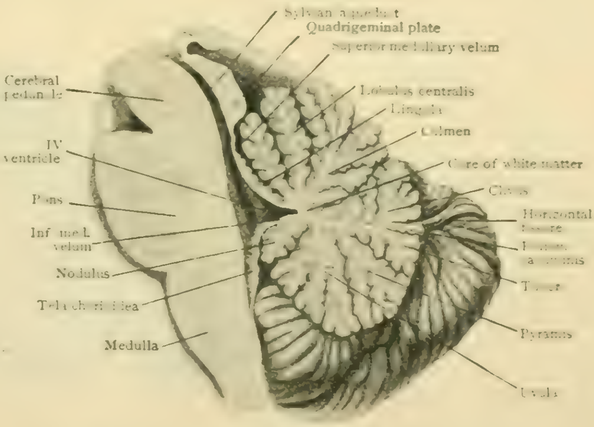
The conventional division into a narrow median part, the **worm**, and the two lateral expansions, the **hemispheres**, while convenient for the description of the cerebellum of man, is not warranted by recent comparative and developmental

studies (Stroud, Elliott Smith, Bradley, Bolk and others), since some details given prominence in human anatomy are of secondary importance, and others of greater morphological significance are only slightly emphasized.

The surface of the cerebellum is divided by the deeper fissures into more or less well defined areas, the *lobules*, each of which is subdivided by shallower clefts into narrow tracts, the *folia*, from 2–4 mm. in width, that usually pursue a curved course within a given lobule and, in a general way, run parallel to one another and to the sulci bounding the tract. On separating the plate-like folia, or on making a section across the plications (Fig. 943), it will be seen that the pattern of the folia is greatly extended by the presence of numerous additional furrows on the deeper and hidden aspects of the leaflets, which are, therefore, ordinarily invisible from the surface. Whether free or sunken, the exterior of the cerebellum is everywhere formed by a *cortical layer* of gray matter, from 1–1.5 mm. thick, that encloses a *medullary layer* of white matter of variable thickness. Owing to this arrangement, sagittal sections of the cerebellum expose an elaborate system of branching tracts of white and gray matter, designated as the *arbor vitæ* (Fig. 938).

The general ellipsoidal mass of the cerebellum, comprising the narrow central vermis and the expanded lateral hemispheres, presents a superior and an inferior surface and rounded anterior and posterior borders. Of these the **anterior border** is indented by a wide groove, the **anterior notch** (incisura cerebelli anterior), which is much larger than the posterior and bounded laterally by the cerebellar hemispheres and behind by the anterior part of the worm. It is occupied by the inferior corpora quadrigemina and the superior cerebellar peduncles and intervening superior medullary velum. The **posterior border** is interrupted by a smaller median indentation, the **posterior notch** (incisura cerebelli posterior), which is bounded on each side by the hemispheres and at the bottom by the hind part of the worm, and contains the crescentic fold of dura known as the falx cerebelli.

FIG. 938.



Mesial sagittal section of brain-stem and cerebellum, showing fourth ventricle, Sylvian aqueduct, and cerebellar worm.

The **upper surface** of the cerebellum is modelled by the overlying tentorium and presents a slight median transversely furrowed ridge that corresponds to the upper surface of the middle division, or worm, and is known as the **vermis superior.** The most elevated part of this surface lies a short distance behind the anterior notch. From this point, designated the *monticulus*, the upper surface slopes gradually downward on each side to the lateral margins of the hemispheres, whilst it falls off more rapidly towards the posterior notch.

The **lower surface** of the cerebellum is much less regular, owing to the presence of a wide median groove, the **vallecula,** that is bordered laterally by the rounded hemispheres and is continuous in front and behind with the anterior and posterior notches. The bottom of the vallecula is occupied by the irregular ridge-like surface of the middle lobe which is here known as the **vermis inferior.** The front of the valley receives the dorsal surface of the medulla.

The cerebellum is incompletely divided into an upper and a lower part by a deep cleft, the **great horizontal fissure** (sulcus horizontalis cerebelli). The sulcus begins in front, at the side of the middle cerebellar peduncle, by the junction of two diverging limbs that embrace the three cerebellar peduncles. It passes usually continuously around the circumference of the cerebellum, but sometimes is interrupted

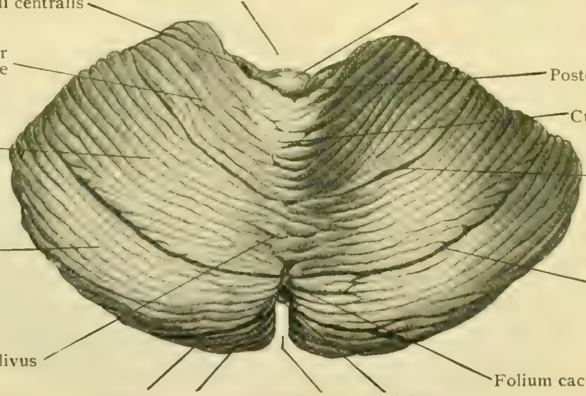
on the worm, and cuts deeply into the lateral and posterior portions of the hemispheres and the worm behind. It is, however, visible on the upper aspect of the cerebellum only for a short distance as it approaches the posterior notch, the remainder of its course being masked by the overhanging border of the hemisphere. Although of cardinal importance in the usual description of the human cerebellum, the great horizontal sulcus is of secondary morphological significance, being a secondary fissure that is developed relatively late in man and feebly or not at all in many other animals.

Both the vermis and the hemispheres are subdivided into tracts, or **lobules,** by the deeper fissures ; these are grouped into **lobes,** in the conventional division of the human cerebellum, by regarding each median division of the worm as associated with a pair of lateral lobules, one for each hemisphere.

LOBES AND FISSURES OF THE UPPER SURFACE.—The subdivisions of the superior worm are, from before backward :—(1) the *lingula*, (2) the *lobulus centralis*, (3) the *culmen*, (4) the *clivus*, and (5) the *folium cacuminis*. With the exception of the lingula, which usually is unprovided with lateral expansions, these median tracts are connected respectfully with (2) the *alæ lobuli centralis*, (3) the *anterior crescentic lobule*, (4) the *posterior crescentic lobule*, (5) the *postero-superior lobule*.

Lobus Lingulæ.—The **lingula,** the extreme anterior end of the superior worm, is not free, but lies attached to the upper surface of the superior medullary velum, covered by the overhanging adjacent part, lobulus centralis, of the worm, which must be displaced to expose the

FIG. 939.



Cerebellum viewed from above.

structure in question. The lingula consists of a tongue of gray matter, composed of five or six rudimentary transverse folia, that overlies the median and lower part of the superior medullary velum and, therefore, is behind the upper part of the fourth ventricle (Fig. 938). Occasionally the lingula is prolonged laterally by rudimentary folia onto the superior cerebellar peduncles, in which case these extensions, known as the **alæ lingulæ (vincula lingulae)** are reckoned as the lateral divisions of the lobus lingulæ.

Lobus Centralis.—The median part of the subdivision includes the second segment of the upper worm, the **central lobule (lobulus centralis)**, that lies chiefly at the bottom of the anterior notch and is visible to only a very limited extent on the upper surface of the cerebellum. The central lobule consists of from 15–18 folia, but not infrequently is divided into two sets of leaflets, which then are collectively somewhat more numerous. It is separated from the lingula by the **precentral fissure** and from the culmen by the **postcentral fissure.** On each side the central folia are prolonged into a triangular tract that curves along the side of the anterior notch, forming a lateral wing-like lobule, the **ala (ala lobuli centralis)**. The two alæ, in conjunction with the median worm-segment, constitute the lobus centralis.

Lobus Culminis.—The third division of the upper worm includes the most prominent part of the upper surface of the hemisphere and, being the crest or summit of the general elevation,

the monticulus, is called the **culmen** (**culmen monticuli**). It is formed by a half dozen or more longer and shorter folia that laterally are continuous with a lunate area of the hemisphere known as the **anterior crescentic lobule** (**pars anterior lobuli quadrangularis**). The latter is the most anterior division of the upper surface of the hemisphere and is a broad crescentic tract limited behind by the **preclival fissure** (**sulcus superior anterior**). The two anterior crescentic lobules and the culmen constitute the lobus culminis.

Lobus Clivi.—The fourth segment of the superior worm slopes rapidly downward from the culmen and receives the name **clivus** (**declive monticuli**). It is separated from the preceding part of the worm by a deep cleft, the central part of the preclival sulcus, which on account of its morphological importance has been called the *fissura prima* (Elliot Smith). Laterally the clivus is connected on each side with the **posterior crescentic lobule** (**pars posterior lobuli quadrangularis**) which resembles the lobule in front and is separated from the one behind by the **postclival fissure** (**sulcus superior posterior**). The clivus and the two posterior crescentic lobules constitute the lobus clivi.

The two crescentic lobules, the anterior and posterior, are regarded by German anatomists as constituting one tract, the *lobulus quadrangularis*, of which the crescentic lobes then become the *pars anterior* and *pars posterior* respectively.

Lobus Cacuminis.—The fifth and last segment of the superior worm, the **folium cacuminis** (**folium vermis**), varies greatly in its details. It consists of a narrow plate that lies between the clivus above and the tuber below and includes usually only one or two, exceptionally as many as five or six, small folia. Sometimes it reaches the level of the adjoining parts of the worm, of which it forms the posterior end ; at other times it is so sunken and buried that its presence can be demonstrated only after separating the clivus and tuber, with either of which it is occasionally joined. At best it is insignificant in comparison with the large crescentic tracts, the **postero-superior lobules**, that it connects. The postero-superior lobule (**lobulus semilunaris posterior**) includes the remainder of the upper cerebellar hemisphere of which it forms the most expanded and lateral tract. In front it is separated from the posterior crescentic lobule by the **postclival fissure** and behind is limited by the great horizontal sulcus, which it overhangs at the side. The folium cacuminis and the two postero-superior lobules constitute the lobus cacuminis.

Lobes and Fissures of the Lower Surface.—The inferior surface of the cerebellum is modified by a wide depression, the vallecula, in the broader upper half of which the posterior surface of the tapering medulla oblongata is received. The bottom of the valley is occupied by the irregular projection of the **inferior worm,** which, when the brain-stem is in place, is covered and not seen, except at its posterior third (Fig. 940). After removal of the pons and medulla by cutting through the cerebellar peduncles and the medullary vela, not only the entire inferior worm is exposed, but also the lobulus centralis and its alæ are seen to good advantage. The inferior worm is separated on each side from the adjacent surfaces of the cerebellar hemispheres by a groove, the **sulcus valleculæ,** that is deepened in its anterior third by the close apposition of its lateral boundary (the tonsil) with the worm.

The connections between the divisions of the inferior worm—from before backward (1) the *nodule*, (2) the *uvula*, (3) the *pyramid* and (4) the *tuber*—and the related parts of the hemisphere are less evident and direct than on the upper surface of the cerebellum. The inferior surface includes four lobules which, from before backward, are: (1) the *flocculus*, (2) the *tonsil*, (3) the *biventral lobule* and (4) the *postero-inferior lobule.*

Lobus Noduli.—The **nodule** (**nodulus**), the most anterior segment of the inferior worm, varies much in size and form, but frequently appears as a rounded triangular prominence, made up of about a dozen folia, that are limited at the sides by the sulcus valleculæ and behind by the postnodular fissure. The relation of the nodule to the inferior medullary velum is somewhat analogous, but less intimate, to that of the lingula to the superior velum. The two structures are more or less extensively united, and the nodule thus excluded from the fourth ventricle by the inferior velum that passes beneath the inferior worm to the apex of the posterior recess of the ventricle (Fig. 938).

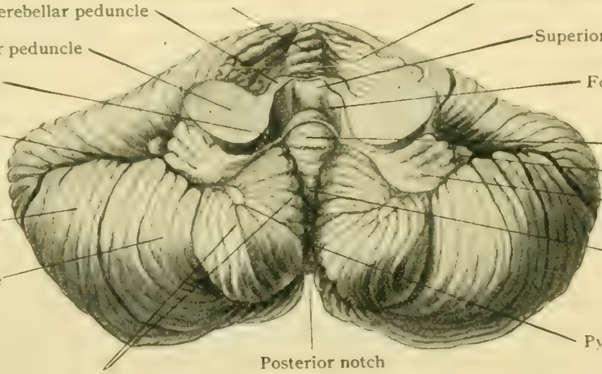
The division of the hemisphere associated with the nodule, the **flocculus**, lies at some distance from the worm and appears, on either side of the cerebellum, as a wedge-shaped group of short irregular folia that project between the middle cerebellar peduncle and the anterior border of the hemisphere. When well developed it may touch the adjacent margin of the anterior crescentic lobule of the upper surface. In addition to the chief floccules,

composed of from ten to twelve leaflets, a second and smaller set, known as the *paraflocculus* or *accessory flocculus*, lies behind and lateral to the main group, often completely buried beneath the overhanging margin of the biventral lobule. In the embryo and in many mammals, the paraflocculus is of considerable size and then shares the relatively much greater development of the flocculus than seen in the adult human brain. The connection between the flocculus and the nodule is established by the lateral part of the inferior medullary velum, which constitutes the *peduncle* of white matter for the floccular folia. In this manner the nodule and the two flocculi, with the intermediate part of the medullary velum, constitute the lobus noduli.

Lobus Uvulæ.—The **uvula**, the next part of the inferior worm, is laterally compressed between the deeper parts of the two tonsils. It varies in form and often appears as a narrow ridge-like structure, triangular on section, of which the median crest alone is seen when the tonsils are in place. The uvula is limited in front by the **postnodular fissure**, and behind by the **prepyramidal**, which laterally, as the **post-tonsillar fissure**, curves outward along the postero-lateral border of the tonsil. The free median surface of the uvula is usually cleft into two or three major subdivisions, which in turn are scored by shallower incisions, so that from six to ten leaflets are present. Some two dozen additional folia mark the hidden lateral surfaces, the entire number being thus usually raised to thirty or more.

The **tonsil** or **amygdala** (**tonsilla**), the segment of the hemisphere associated with the uvula, is a pyramidal mass lying between the worm and the biventral lobule and forming the central zone of the general quadrant embracing the lower surface of the entire hemisphere. The free convex inferior surface of the tonsil is irregularly triangular in outline and bounded by a relatively straight median margin (along the sulcus valleculæ), an outwardly arched postero-lateral

FIG. 940.



Inferior aspect of cerebellum, after removal of pons and medulla.

border (along the curved posttonsillar fissure) and a notched anterior edge. This, the chief surface, is marked by a straight furrow that extends from the indentation on the anterior border backward and inward and marks a line along which the curved folia, from nine to fourteen in number, abut. Of the other surfaces bearing folia—the median, posterior and lateral—that directed towards the uvula (median) alone is entirely unattached, the others, with the superior, receiving the stalk of white matter. The deeper part of the tonsil is subdivided, so that on removing the larger and more superficial portion of the amygdala a buried and accessory segment of its mass often remains. Beneath (really above) the tonsil, a narrow tongue, marked with short transverse folia, stretches from the posterior part of the uvula across the roof of the space occupied by the tonsil to the upper and lateral part of the amygdala. This tract, known as the **furrowed band** (**alae uvulae**) connects the worm with the hemisphere and thus joins the uvula and the two tonsils into the lobus uvulæ. The posterior border of the furrowed band is free, whilst its anterior one is continuous with the inferior medullary velum. After removal of the tonsil by cutting through its supero-lateral stalk, a deep recess is left, which is bounded medially by the uvula and laterally by the biventral lobule and roofed in by the furrowed band and the inferior velum. To this space the older anatomists gave the name, "bird's nest" (*nidus avis*).

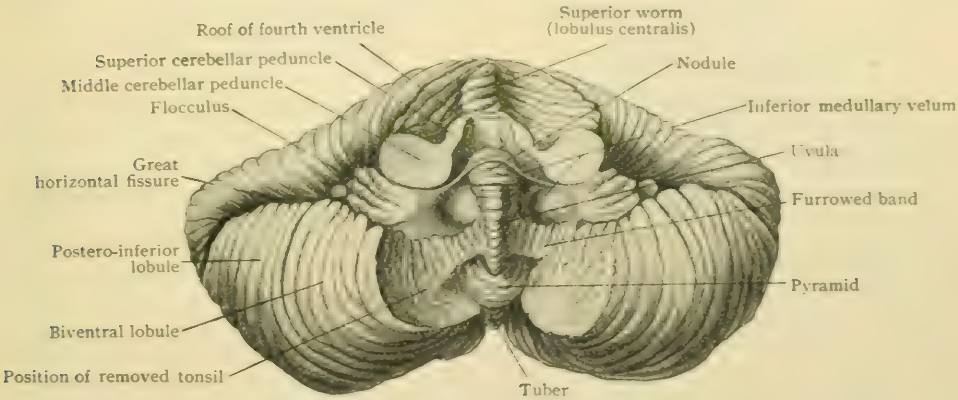
Lobus Pyramidis.—The **pyramid** (**pyramis**) the segment of the inferior worm lying behind the uvula and in front of the tuber, is partly covered by the tonsils. Posterior to the latter

it is seen at the bottom of the vallecula between the median areas of the biventral lobules, where it forms the most prominent division of the worm. It is an elongated club-shaped mass, attached by a narrow stalk and separated from the adjacent parts of the worm by the **prepyramidal** and **postpyramidal fissures** and from the hemispheres by the sulci valleculæ. The convex inferior surface usually presents from 5–8 superficial folia, those towards the uvula being longer than those directed towards the tuber. After removal of the tonsil, a narrow band, the connecting ridge, is seen passing, on each side, from the anterior part of the pyramid to the adjacent mesial end of the biventral lobe, which, in this manner, is brought into relation with the worm.

The **biventral lobule** (**lobulus biventer**) ordinarily consists, as its name implies, of two subdivisions, which together appear on the surface as a curved zone, the extremities of which are more contracted than the intermediate tract that attains a breadth of 15 mm. and more. The details of form and foliation are quite variable, the lobule being not only sometimes much broader than usual, but farther subdivided, so that three, instead of two, tracts are included. The broader outer end of the lobule reaches the anterior margin of the hemisphere, and the narrowed inner end the vallecula, in consequence of which the component superficial concentric leaflets, some twelve to sixteen in number, are compressed and thinner as they approach the sulcus valleculæ. The biventral lobule is separated from the tonsil, around which it curves, by the lateral extension of the **prepyramidal** or **post-tonsillar fissure** and is limited behind by the arched **postpyramidal fissure**.

Lobus tuberis.—The **tuber** (**tuber vermis**) forms the most posterior division of the inferior worm and lies beneath the great horizontal fissure when that sulcus is continuous across the mid-line. When the folium cacuminis is small and buried, the tuber comes into close relation with the lower end of the clivus, the three divisions of the worm just mentioned all springing from a common stalk of white matter. The tuber is of a general

FIG. 941.



Cerebellum, seen from below after removal of tonsils.

conical form, with the base directed towards the pyramid, from which it is separated by the postpyramidal fissure, and its apex projecting into the posterior cerebellar notch. It presents a few, from 2–4, superficial folia, which model the posterior pole of the worm, as viewed from behind and above.

The tuber is directly connected on each side with a considerable crescentic tract, the **postero-inferior lobule** (**lobulus semilunaris inferior**), that is limited in front by the lateral extension of the postpyramidal fissure (**sulcus inferior anterior**) and behind by the great horizontal fissure. After emerging from the sulcus valleculæ, the folia rapidly expand into a lunate tract, from 15–25 mm. in its widest part, that forms the immediate posterior border of the hemisphere. The postero-inferior lobule is usually described as divided into two parts, an anterior and a posterior, by the **postgracile fissure** (**sulcus inferior posterior**), but quite frequently further subdivision of the superficial folia, from 12–18 in number, results in defining three sublobules. The anterior of the two conventional subdivisions is a narrow tract of fairly uniform width to which the name *lobulus gracilis* is applied. The lunate posterior area, much less regular in contour and foliation, is known as the *inferior crescentic lobule* (**lobulus semilunaris inferior**) and sometimes presents evidence of subdivision into two secondary crescentic areas. The postero-inferior lobules and the tuber constitute the **lobus tuberis**.

In recapitulation, the foregoing cerebellar lobes, with their component worm-segments and associated hemisphere-tracts, and the intervening fissures may be followed in order, from the anterior and superior end of the worm to its front and lower pole. Although not agreeing with a morphological division, such grouping[1] is convenient as applied to the adult human cerebellum.

THE LOBES OF THE CEREBELLUM.

WORM	HEMISPHERE	LOBE
Lingula	(Vinculum lingulæ)	**Lobus lingulæ**
Sulcus precentralis		
Lobulus centralis	Ala lobuli centralis	**Lobus centralis**
Sulcus postcentralis		
Culmen monticuli	Lobulus lunatus anterior	**Lobus culminis**
Sulcus preclivalis		
Clivus monticuli	Lobulus lunatus posterior	**Lobus clivi**
Sulcus postclivalis		
Folium cacuminis	Lobulus postero-superior	**Lobus cacuminis**
Sulcus horizontalis		
Tuber vermis	Lobulus postero-inferior	**Lobus tuberis**
Sulcus postpyramidalis		
Pyramis	Lobulus biventer	**Lobus pyramidis**
Sulcus prepyramidalis		
Uvula	Tonsilla	**Lobus uvulæ**
Sulcus postnodularis		
Nodulus	Flocculus	**Lobus noduli**

Architecture of the Cerebellum.—With the exception of where the robust peduncular collections of nerve-fibres enter the hemispheres and immediately above the dorsal recess of the fourth ventricle, the cerebellum is everywhere covered by a continuous superficial sheet of cortical gray matter which follows and encloses the subdivisions of the white core. The latter, as exposed in sagittal sections of the hemisphere, is seen to be a compact central mass of white matter, from which stout stems radiate into the various lobules. From these, the primary stems, secondary branches penetrate the subdivisions of the lobules, and from the sides of these, in turn, smaller tracts of white matter, the tertiary branches, enter the individual folia. Over these ramifications of the white core, the cortical gray matter stretches as a fairly uniform layer, about 1.5 mm. thick, that follows the complexity of the folia and fissures. The resulting arborization and the contrast between the white and gray matter are particularly well shown in sections passing at right angles to the general direction of the folia. This disposition is especially evident in median sagittal sections (Fig. 938), where the less bulky medullary substance of the worm, also known as the *corpus trapezoideum*, and its radiating branches produce a striking picture, to which the name, *arbor vitæ cerebelli*, is applied.

The Internal Nuclei.—In addition to and unconnected with the cortical layer, four paired masses of gray matter, the *internal nuclei*—one of considerable size and three small—lie embedded within the white matter.

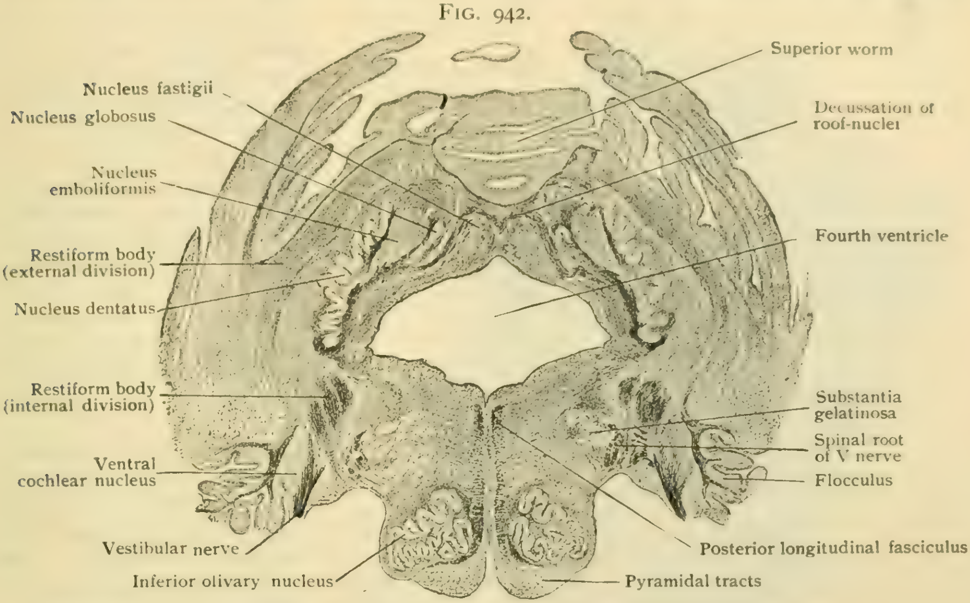
The dentate nucleus (nucleus dentatus), or *corpus dentatum*, the largest and most important of the internal nuclei, consists of a plicated sac of gray matter (Fig. 951) and resembles in many respects the inferior olivary nucleus. Like the latter, it is a crumpled thin lamina of gray matter which is folded on itself into a pouch, enclosing white matter, through whose medially directed mouth, termed the *hilum*, emerge many fibre-constituents of the superior cerebellar peduncle. The dentate nucleus never encroaches upon the core of the worm, but lies embedded within the anterior part of the median half of the hemisphere, with its long axis

[1] Modified from Schäfer and Thane in Quain's Anatomy, Tenth Edition.

directed forward and somewhat inward and, therefore, slightly oblique to the sagittal plane. Anteriorly the nucleus reaches the level of a frontal plane passing through the precentral fissure; laterally it extends to about the middle of the hemisphere (Ziehen); whilst medially its postero-inferior end comes into such close relation with the fourth ventricle that a slight elevation, *eminentia nuclei dentati*, is produced on the lateral ventricular wall. In its longest (antero-posterior) dimension the nucleus measures from 15–20 mm., and in breadth about half as much.

Of the other paired internal collections of gray matter—the nucleus fastigii, the nucleus emboliformis and the nucleus globosus—the **nucleus fastigii,** or the **roof nucleus,** is the best defined. It lies within the core of the worm, in the lower part of the corpus trapezoideum, very close to the mid-line and to its fellow of the opposite side. In its general form the nucleus is egg-shaped, with the posterior pole somewhat prolonged, and in its sagittal diameter measures about 10 mm. and in the transverse dimension about half as much. The nucleus extends from the base of the

FIG. 942.



Section across upper part of fourth ventricle, showing internal cerebellar nuclei; new-born child. × 3⅓. Weigert-Pal staining. Preparation by Professor Spiller.

lingula to the stem of the pyramid, and in frontal sections (Fig. 942) appears circular in outline and closely related with fibre-tracts that in part end in the nucleus of the opposite side.

The **nucleus emboliformis,** or **embolus,** is an irregular wedge-shaped plate of gray matter that partly closes the hilum of the dentate nucleus, in much the same manner that the median accessory olivary nucleus obstructs the mouth of the chief olivary nucleus. In its sagittal diameter it measures about 15 mm., and in the vertical one approximately one-fourth as much; it decreases in thickness from about 3 mm. in front to a slender wedge behind. The embolus rests upon the superior cerebellar peduncle, its front end extending to within a few millimeters of the precentral fissure and its posterior pole reaching almost as far back as the dentate nucleus, with which it is united by a limited connection.

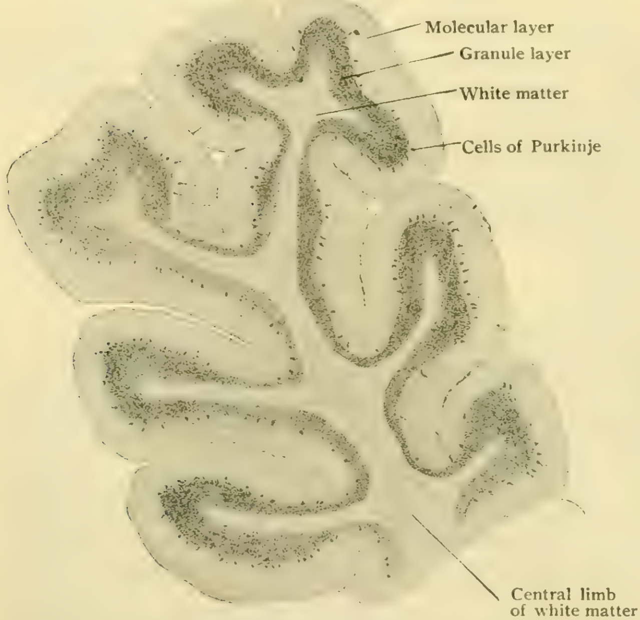
The **nucleus globosus** lies close to the medial side of the embolus, between the latter and the roof nuclei. In its general form the nucleus is comparable to a sphere attached to a sagittally directed stalk (Ziehen). The globular head, about 5 mm. in diameter and somewhat transversely compressed, lies above the tonsil and is continuous with the stalk that extends backward for a distance of about 8 mm.

By means of uncertain and limited attachments the nucleus globosus is loosely connected with the roof nucleus and the embolus, and also joins the postero-inferior

part of the dentate nucleus. Since the latter and the embolus are likewise slightly connected, it is evident that all four internal nuclei are more or less continuous masses of gray matter.

In **structure** the internal nuclei differ markedly from the cerebellar cortex, since in the main they are composed of irregularly disposed nerve-cells of one kind interspersed with numerous nerve-fibres. The **dentate nucleus** contains cells from .020–.030 mm. in diameter whose bodies are angular or stellate in outline and pigmented in varying degrees. Their processes are usually so disposed that the axones pass into the medullary substance enclosed by the plicated lamina and the dendrites into the surrounding white matter of the hemisphere. Numerous fibres enter the dentate body from without, many being the axones of the Purkinje cells, and break up into a rich plexus within the folded sheet of gray substance. Since the **nucleus emboliformis** and the **nucleus globosus** are only incompletely isolated parts of the dentate nucleus, their structure corresponds closely with that of the chief mass.

FIG. 943.



Transverse section of cerebellar folium, showing relations of cortex to underlying white matter. × 10.

The **roof-nuclei**, on the contrary, possess cells of much larger size (.040 to .080 mm.), more rounded form and greater uniformity in tint, although their general yellowish brown color implies less intense pigmentation. Numerous strands of nerve-fibres subdivide the nucleus into secondary areas, while some large transversely coursing bundles establish a decussation with the roof-nucleus of the opposite side.

The Cerebellar Cortex.—When the folia are sectioned at right angles to their course, each leaflet composing the characteristic arborization is seen to consist of a central tract of white medullary substance, covered in by the continuous superficial sheet of cortical gray matter. The latter, usually somewhat less than one millimeter in thickness, includes two very evident strata—the outer and lighter *molecular layer* and the inner and darker *granule layer*.

The **molecular layer** is of uniform thickness, about .4 mm., and contains three varieties of nerve-cells—the Purkinje cells, the basket cells and the small cortical cells. The **Purkinje cells,** the most distinctive nervous elements of the cerebellum, occupy the deepest part of the molecular layer, where they are disposed in a single row along the outer boundary of the subjacent granular layer. The cells are most numerous and more closely placed upon the summit of the folium and fewer and more scattered along the fissures, in which situation they are also often of less typical pyriform shape. They possess a large flask-like body, about .060 mm. in diameter, from the pointed and outwardly directed end of which usually one, sometimes more, robust dendritic process arises. The chief process, relatively thick and very short, soon divides into two branches, which at first diverge and run more or less horizontally and then turn sharply outward to assume a course vertical to the surface and undergo repeated subdivision. The arrangement of the larger *dendrites* is very striking and recalls the branching of the antlers of a deer. The smaller processes arise at varying

and often acute angles, the completed division resulting, as displayed by silver impregnations (Fig. 944), in an arborization of astonishing richness and extent that often reaches almost to the outer boundary of the molecular layer. The dendritic ramification of each cell is limited, however, to a narrow zone extending across the folium and, hence, when examined in sections cut parallel with the plane of the folium, these expansions are found to be confined to tracts separated by zones of the molecular layer that are uninvaded by the dendrites of the Purkinje cells. The *axones* of the latter arise from the rounded basal or deeper end of the pyriform body and at once enter the granular layer, which they traverse to gain the white medullary core of the folium. In their course the axones give off a few recurrent collaterals that end within the molecular layer in the vicinity of the bodies of the cells of Purkinje.

The **stellate** or **basket cells** lie at different planes, but chiefly within the deeper half of the molecular layer. They possess an irregular stellate body, from .010–.020 mm. in diameter, from which several dendrites radiate. Their chief feature of interest is the remarkable relation of the axone, which extends across the folium in an approximately horizontal plane along and to the outer side of the row of the Purkinje cells. During this course the axone gives off from three to six collaterals that descend to the cells of Purkinje, whose bodies they surround and enclose with a basket-like arborization, the terminal ramification of the main process itself ending in like manner. By means of this arrangement each basket cell is brought into close relation with several of the larger elements.

Fig. 944

Purkinje cell from silver preparation of cerebellar cortex; *A*, axone. × 120.

The **small cortical cells** occur at all depths, but are most numerous in the more superficial planes, in which they appear as diminutive multipolar elements with radiating dendrites and axones of uncertain destination.

The **granule layer,** of a rust-brown tint when fresh and deeply colored in stained preparations, is thickest on the summit of the folia and thinnest opposite the bottom of the sulci. While sharply defined from the overlying molecular layer, it is less clearly distinguished from the medullary substance. The granular layer contains two varieties of nerve-cells—the granule cells and the large stellate cells.

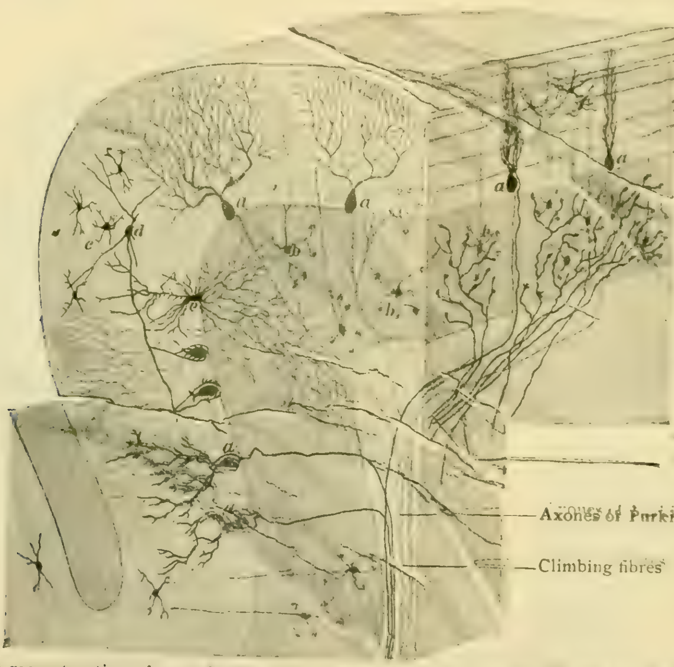
The **granule cells** are very small (.007–.010 mm.) and numerous and so closely packed that they confer upon the stratum its distinctive density. They are provided with from three to six short radiating dendritic processes that end in peculiar claw-like arborizations in relation with other granule cells. The axones, directed towards the surface, enter the molecular layer, within which, at various levels corresponding to the depth of the cells, they undergo T-like division. The two resulting branches run horizontally and lengthwise and in the folium—that is, parallel to the surface and at right angles to the plane of expansion of the dendrites of the Purkinje cells, through the arborizations of which they find their way and with which they probably come into close relation.

The **large stellate cells** are present in varying number, but are never numerous. They lie close to the outer limit of the granule layer and possess a cell-body of uncertain and irregular form, from .030–.040 mm. in diameter, from which usually

several richly branched dendrites pass in various directions, but largely into the molecular layer. The axone is most distinctive, as very soon after leaving the cell it splits up into an arborization of unusual extent and complexity, which, however, is confined to the granular layer. These cells, therefore, belong to those of type II (page 998). Since by their processes they are brought into intimate relation with a number of other neurones, the elements under consideration are probably of the nature of association cells.

The **nerve-fibres** encountered within the cerebellar cortex (Fig. 945) comprise three chief varieties. (1) The first of these includes the axones of the cells of Purkinje which contribute an inconsiderable portion of the fibres passing from the cerebellar cortex to other parts, either of the cerebellum itself or of the cerebrum and brain-stem. (2) The **moss-fibres** destined especially for the granular layer, which upon enter-

FIG. 945.



Diagrammatic reconstruction of part of folium, illustrating relations of nerve cells and fibres of cerebellar cortex; folium is shown cut transversely and longitudinally; *a*, Purkinje cells; *b*, granule cells; *c*, small cortical cells; *d*, basket cells; *e*, large stellate cells.

ing the latter break up into a number of branches that bear, either at the points of division or at their ends, thickenings from which bundles of short diverging twigs are given off. By this arrangement each moss-fibre ends in relation with a large number of granule cells. (3) The **climbing-fibres**, so named (Cajal) on account of their tortuous and vine-like course, ascend through the granular to the molecular layer, to which they are chiefly if not exclusively distributed, where they entwine and cling to the primary and secondary dendritic processes of the Purkinje cells. Additional fibres encountered within the granule layer are, evidently, the axones of the granule cells and the collaterals of the cells of Purkinje, whilst a large proportion of the fibres within the molecular layer are formed by the ramifications of the axones of the granule cells and of the basket cells.

The **neuroglia** forms a supporting framework of considerable density both within the white matter and the cortex. As seen in preparations colored with the usual nuclear stains, the neurogliar elements are conspicuous within the granule layer, to whose numerous small nuclei they contribute no small part. The cells occupying the outer zone of the granule layer exhibit a peculiar arrangement of their processes that in a measure recalls the disposition of those of the Purkinje cells. In

addition to a short and uncertain centrally directed process, the irregular cell gives off a brush-like group of fibrillæ which penetrate the molecular layer, seldom branching, as far as the free surface of the folium, when they end beneath the pia in expansions that become condensed and unite into a delicate limiting membrane. The radial disposition of the neuroglia fibres, as well as of the Purkinjean dendrites, climbing fibres and the larger blood-vessels, confer upon the molecular layer a vertical striation that is often marked.

The Medullary Substance.—The white matter composing the core of the cerebellar hemispheres exhibits several fairly definite subdivisions, among which may be distinguished :

1. The *subcortical layer*, from .2–.5 mm. in thickness, that extends beneath the granule layer, parallel to the surface, and sweeps around the bottom of the deeper fissures. Within the series of festoons thus formed lie the association tracts that connect the folia and lobules of the same hemisphere.

2. The *commissural tracts*, of which the larger lies in front of the dentate nucelus and the smaller behind this nucleus, are continued across the mid-line and into the opposite hemisphere as the anterior (superior) and the posterior (inferior) cerebellar decussations.

3. The *peridentate stratum* that comprises a fibre-complex that surrounds the nucleus dentatum.

Within the medullary substance of the worm, lie :

1. The *superior cerebellar commissure*, a robust tract of transversely coursing fibres that passes in front of the roof-nucleus and, beyond the worm, expands on each side into the main limbs of the medullary tree. It is chiefly by the decussating fibres within this commissure that the cortex of the two hemispheres is connected.

2. The *inferior cerebellar commissure* passes behind the roof-nucleus and consists of a number of small transversely coursing bundles.

3. The *decussation of the roof-nuclei* constitutes a commissural and decussating tract distinct from that of the cerebellar commissures just described. The rounded bundles traverse the roof-nucleus, particularly its superior (anterior) part, more distally skirting its dorsal margin and, still farther backward, invading the beginning of the horizontal medullary limb.

4. The *median sagittal bundle* extends from the superior medullary velum beneath the roof-nucleus into the medulla of the worm ; above, these fibres are continued upward through the velar frenum and into the inferior quadrigeminal colliculus.

In addition to the foregoing tracts, the central parts of the branches of the medullary tree, not only of the hemispheres but also of the worm, are occupied by longitudinally coursing fibres that pass directly into the white core, and thence are continued into the cerebellar peduncles as the afferent and efferent paths by which the cerebellar cortex is brought into relation with other parts of the brain and spinal cord.

Fibre-Tracts of the Cerebellar Peduncles.

Repeated mention has been made of the three robust arms of white matter, the peduncles, that enter the medullary substance of the cerebellum and serve to transmit the fibre-tracts that connect the cerebellum with the cerebrum, the brain-stem and the spinal cord. The general features of the inferior, middle and superior cerebellar peduncles are described in connection with the medulla, the pons and the mid-brain respectively. It will be convenient in this place, in connection with the cerebellum, to consider more in detail the constituents of these important pathways.

The Inferior Cerebellar Peduncle.—This robust stalk (**corpus restiforme**), also known as the **restiform body**, includes not only the tracts connecting the cerebellum with the spinal cord, but also those that link the cerebellum and the medulla. Two divisions, the *spinal* and the *bulbar*, are therefore often recognized.

The chief constituents of the inferior peduncle are :

1. The **direct cerebellar tract**, the fibres of which arise from the cells of Clarke's column, course through the lateral part of the inferior peduncle and end in the cortex of the anterior part of the superior worm on the same side, some fibres reaching the opposite side of the worm by way of the superior commissure.

2. The **arcuate fibres** (anterior and posterior superficial), from the gracile and cuneate nuclei of the opposite and the same side. Additionally, perhaps, some fibres are continued, without interruption in the medullary nuclei, from the posterior fasciculi of the cord. All of these, direct and indirect, end chiefly within the cortex of the superior worm of the same and the opposite side.

3. The **olivo-cerebellar fibres**, chiefly from the opposite inferior olivary nucleus but to a limited extent also from the nucleus of the same side. They contribute in large measure to the formation of the lateral part of the restiform body and, on reaching the cerebellum, end within the cortex of the hemisphere and worm, as well as within the fibre-complex enveloping the nucleus dentatus. Whilst for the most part afferent, it is probable that some of the fibres within the tract are efferent and hence conduct impulses in the contrary direction.

4. **Fibres from the nucleus lateralis** of the medulla, which pass to the cortex of the cerebellar hemisphere.

5. **Fibres from the arcuate nucleus**, which pass to the cerebellar cortex.

6. The **nucleo-cerebellar tract**, comprising fibres from the cells within the reception-nuclei of the trigeminal, facial, vestibular, glosso-pharyngeal and vagus nerves. The tract occupies the median part of the peduncle and ends chiefly in the roof-nucleus of the same and of the opposite side.

7. Other fibres pass in reversed direction from the roof-nucleus to the dorso-lateral (Deiters') vestibular nucleus of the auditory nerve and thence, as the **vestibulo-spinal tract**, descend through the medulla into the antero-lateral column of the cord.

8. Additional vestibular (and, possibly, other sensory) fibres pass without interruption by way of the restiform body to the roof-nuclei and constitute the **direct sensory cerebellar tract** of Edinger.

The Middle Cerebellar Peduncle.—The middle peduncle (**brachium pontis**), which continues the pons laterally into the medulla of the cerebellum, transmits the fibres whereby the impulses arising within the cerebral cortex are conveyed to the cerebellum. It does not establish direct connections between the cerebellar hemispheres, as it might be supposed to do from its transverse position and intimate relation with the cerebellar hemisphere, such bonds from side to side passing exclusively by way of the commissures within the worm.

The chief constituents of the middle peduncle are :

1. The **continuations of the fronto-cerebellar** and **temporo-occipito-cerebellar tracts**, the fibres of which arise from the cortical cells within the frontal, temporal and occipital lobes respectively, descend through the internal capsule and the cerebral crus, and end around the cells of the pontile nucleus. From the latter cells arise the **ponto-cerebellar fibres**, the immediate constituents of the middle peduncle, that for the most part cross the mid-line and traverse the peduncle to be distributed to all parts of the cortex of the hemispheres and of the worm and, possibly, also to the nucleus dentatus. A small number of these fibres do not decussate, but pass from the pontile cells to the cerebellar cortex of the same side. It should be remembered that the pontile nuclei are also influenced by cortical impulses that descend by way of the pyramidal tracts, since numerous collaterals from the component fibres of these motor paths end around the pontile cells.

2. Efferent **cerebello-pontile fibres**, distinguished from the afferent fibres by their larger diameter, originate as axones of the Purkinje cells and pass from the cerebellar cortex through the middle peduncle into the dorsal part of the pons, where, after crossing the mid-line, they are believed (Bechterew) to end within the tegmentum in relation with the cells of the nucleus reticularis tegmenti close to the raphe. The assumption, often made, that many of the efferent cerebello-pontile fibres end around the cells of the nucleus pontis, lacks the support of the more recent observations.

The Superior Cerebellar Peduncle.—The superior peduncle (**brachium conjunctivum**) forms, with its fellow of the opposite side, the important pathway by which the cerebellar impulses are transmitted to the higher centres and, eventually, to the cerebral cortex, as well as indirectly to the spinal cord.

Its chief constituents are (1) the **cerebello-rubral** and (2) the **cerebello-thalamic fibres** collectively known as the **cerebello-tegmental tract**. The principal components of the latter are the fibres arising from the cells of the dentate nucleus, which, emerging from the hilum of the corpus dentatum and receiving augmentations from the roof-nucleus and, probably, to a limited extent from the cortex of the worm, become consolidated into the rounded arm that skirts the supero-lateral boundary of the fourth ventricle. Converging with the tract of the opposite side towards the mid-line, the peduncle sinks ventrally and disappears beneath the corpora quadrigemina, many of its fibres continuing their course through the tegmentum of the cerebral peduncle into the subthalamic region and the thalamus. On reaching a level corresponding to that of the upper third of the inferior colliculi of the quadrigeminal bodies, the tracts of the two sides meet and begin to intermingle, the **decussation of the superior peduncle** (Fig. 960) thus estab-

lished being best marked opposite the superior colliculi. Above this decussation, which, however, does not involve all of its fibres, since some ascend on the same side, the cerebello-tegmental tract is in large measure interrupted in the red nucleus (nucleus tegmenti ruber), that lies within the upper part of the tegmental area of the cerebral crus (page 1114). The fibres not ending around the cells of this nucleus are continued through the subthalamic region into the thalamus, in relation to the cells of which they terminate.

Of those ending within the red nucleus, the majority transfer their impulses to fibres that arise from the rubral neurones and thence proceed to the thalamus in company with the uninterrupted fibres. From the thalamus the impulses are carried by the thalamo-cortical paths (page 1122) to the cerebral cortex, the cells of which are thus influenced by the coördinating reflexes of the cerebellum.

A considerable part of the impulses conveyed to the red nucleus is diverted by the axones of some of its neurones into an entirely different path, namely, the **rubro-spinal tract,** which decussates and carries impulses from the cerebellum through the brain-stem and antero-lateral column of the cord to the anterior root-cells of the spinal nerves.

From the foregoing descriptions it is evident that by means of its peduncles the cerebellum receives no small part of the sensory impulses collected by the spinal and cranial nerves and, in turn, issues the impulses necessary to maintain coördination and equilibrium. Such impulses may be entirely reflex, as in the case of movements performed automatically, in which instance the circuit is (*a*) from the spinal cord and the medulla, directly or indirectly, to the cerebellum chiefly by way of the tracts within the inferior cerebellar peduncles; (*b*) from the cerebellum to the motor root-cells within the brain-stem and the cord by way of the cerebello-vestibulo-spinal tract and the cerebello-rubro-spinal tract.

When the necessity arises for voluntary efforts in maintaining equilibrium, the circuit includes impulses from the cerebral cortex, in which case the cerebello-rubro-thalamo-cortical tract and the cortico-spinal tract form the most direct path. As accessory to this an indirect path, impulses by way of the cortico-ponto-cerebellar and the cerebello-rubro-spinal tracts, may be assumed as probably taking part in securing the necessary motor balance.

Fig. 946

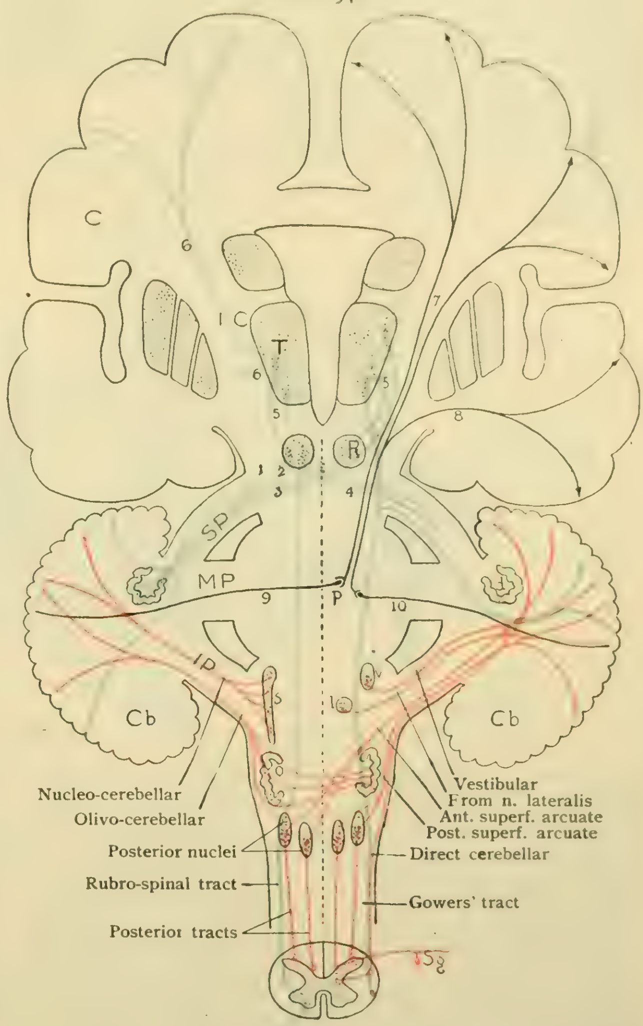


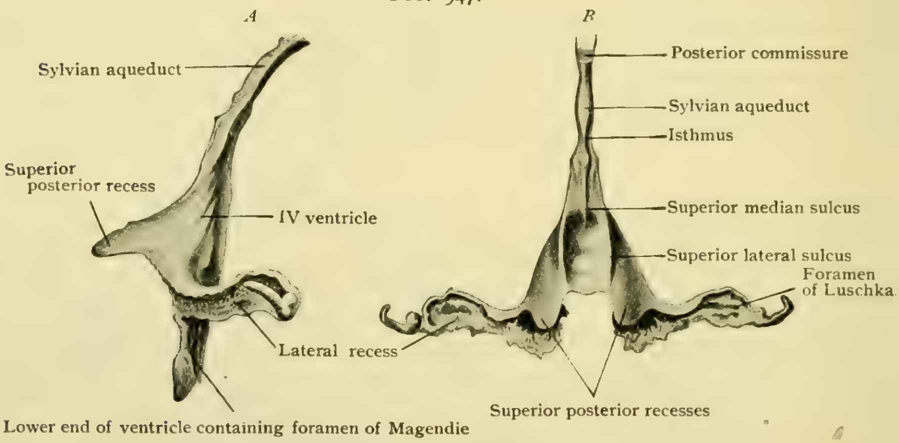
Diagram illustrating chief components of cerebellar peduncles; fibres passing by inferior peduncle (IP) are red; those by superior peduncle (SP) are blue; those by middle peduncle (MP) are black; C, cerebrum; T, thalamus; IC, internal capsule; R, red nucleus; Cb, cerebellum; d, dentate nucleus; p, pontine nucleus; v, l, o, vestibular, lateral, and inferior olivary nuclei; s, reception nuclei of sensory nerves; Sg spinal ganglion; 1, 2, cerebello-rubral fibres, one of which (4) is continued downward as rubro-spinal tract; 3, cerebello-thalamic; 5, rubro-thalamic; 6, thalamo-cortical; 7, fronto-pontine; 8, temporo-occipito-pontine; 9, 10, ponto-cerebellar fibres.

THE FOURTH VENTRICLE.

The fourth ventricle (**ventriculus quartus**), the persistent and modified hind-brain segment of the primary neural canal, is an irregular triangular space between the pons and the medulla in front, and the inferior cerebellar worm and the superior and inferior medullary vela behind. The lateral boundaries are contributed by the superior and inferior cerebellar peduncles. Its long axis is approximately vertical and about 3 cm. in length, measured from the lower extremity, where the ventricle is directly continuous with the central canal enclosed within the medulla and spinal cord, to the upper end, where it passes into the aqueduct of Sylvius. Its width is greatest (about 2.75 cm.) somewhat below the middle, where this dimension is increased by two lateral recesses, one on each side, that continue the cavity of the ventricle over the restiform body.

The **Floor of the Fourth Ventricle.**—The floor of the ventricle, really its anterior wall, when viewed from behind after removal of the cerebellum and the medullary vela, appears as a lozenge-shaped area (**fossa rhomboidea**). The upper half of the floor is formed by the dorsal or ventricular surface of the pons and is bounded

FIG. 947.



Cast of cavity of fourth ventricle; *A*, from the side; *B*, from above. × ⅘. (*Retzius.*)

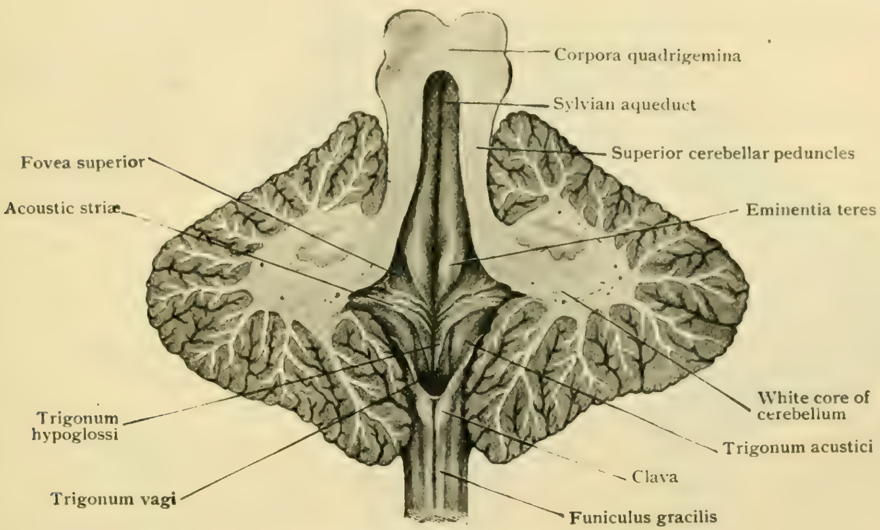
laterally by the upwardly converging superior cerebellar peduncles. The lower half is formed by the ventricular surface of the open part of the medulla and is bounded by the downwardly converging inferior cerebellar peduncles and the clavæ. The narrow lower angle of the rhombic area, long known as the *calamus scriptorius*, corresponds to the interval between the clavæ, where the central canal of the cord communicates with the fourth ventricle. The upper angle, situated beneath the superior medullary velum and, therefore, described by some anatomists as belonging to the isthmus of the hind-brain (rhombencephalon), marks the lower end of the Sylvian aqueduct. The length of the rhombic fossa is about 3 cm., and its breadth, greatest at the level of the auditory nerve, is about 2 cm.

In consequence of the elevation of its lateral boundaries, the floor appears sunken and corresponds approximately with the frontal plane, being almost vertical. It is divided into symmetrical lateral portions by a **median groove** (**sulcus medianus longitudinalis sinus rhomboidalis**), and into an upper and a lower half by transverse markings, the **acoustic striæ** (**striae acusticae**), which on each side arise from the nuclei of the cochlear nerve, wind over the restiform body and cross the floor of the ventricle to disappear within the median furrow. At its lower end, where it sinks into the central canal of the cord, the median groove becomes somewhat wider, the resulting depression being sometimes designated the *ventriculus Arantii*. Roofing in the ventricle at this point and bridging the cleft separating the posterior columns, lies a thin triangular sheet of loose vascular tissue, the **obex**, which laterally is continuous

with the delicate roof-membrane, known as the **tela chorioidea.** Toward its upper end the longitudinal furrow presents a second expansion, the *fossa mediana.* The acoustic striæ vary greatly in distinctness and arrangement, sometimes appearing as well-marked bands that cross the ventricular floor with little divergence, or they may constitute a fan-shaped group in which the strands may be irregularly disposed or even overlap ; in other cases they may be much less distinct on one side, or so feebly marked on both as to be unrecognizable. Quite frequently one band diverges from the others and crosses the floor obliquely upward and outward. This strand, specially designated as the **conductor sonorus,** is seldom equally distinct on the two sides, being usually better seen on the left.

The **inferior division of the ventricular floor,** that lying below the acoustic striæ, presents three general fields of triangular outline. The one next the median groove, with its base above and its apex directed towards the lower angle of the ventricle, which it almost reaches, is the **trigonum hypoglossi,** so called from the fact that it partly overlies the nucleus of the twelfth nerve. Lateral from the last

FIG. 948.



Floor of fourth ventricle exposed after removal of its roof by frontal section.

named area is a somewhat depressed triangular field of darker color, the apex of which is placed above, near the acoustic striæ, and the base below ; this field is known as the **ala cinerea,** from the dark tint imparted to it by the pigmented cells lying beneath, and as the **trigonum vagi,** in recognition of the subjacent glosso-pharyngeo-vagus nucleus. The remainder of the inferior division of the ventricular floor includes an elevated triangular field, the **trigonum acustici,** that is part of the larger tract, the **area acustica,** which occupies not only the lateral angle of the rhomboidal fossa, where it is crossed by the acoustic striæ, but also the adjacent portion of the superior division of the ventricular floor. Laterally, the acoustic area presents a distinct elevation, the **tuberculum acusticum,** which, together with the adjacent part of the trigonum acustici, is related to the nuclei of the cochlear nerve ; the more median portion of the acoustic area, on the other hand, belongs to the vestibular division.

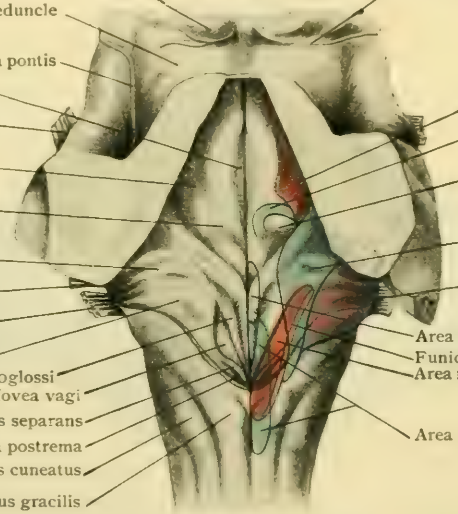
The **superior division of the ventricular floor,** above the acoustic striæ, is marked on each side of the median groove by a prominent elevation, the **eminentia teres,** which below is continuous with the trigonum hypoglossi and above narrows and fades away towards the floor of the Sylvian aqueduct. Laterally the eminence is bounded by a depressed area, the **fovea superior,** which is the expanded upper part of a second longitudinal furrow, the **sulcus lateralis,** that defines the outer limit of the eminentia teres and below is continued into the depressed trigonum vagi, to which the name, **fovea inferior,** is sometimes applied. Above and to the outer side of the

superior fovea, the ventricular floor presents a slightly sunken field, the **locus cœruleus,** which extends upward to the Sylvian aqueduct and in fresh preparations possesses a bluish gray tint in consequence of the deeply pigmented cells of the underlying substantia ferruginea (page 1081) showing through the ependymal layer.

The accurate description of the surface markings of the ventricular floor given by Retzius,[1] has been supplemented by Streeter's[2] careful study of the relation of these details to the underlying structures. The most important results of these observations, which have materially advanced our understanding of this important part of the brain-stem, may here find mention.

The **trigonum hypoglossi** is seen, especially when examined under fluid with a hand-lens, to include two subdivisions, a narrow median and a broader lateral. The first of these is convex, about 5 mm. long by 1 mm. wide, and corresponds to the rounded upper end of the nucleus of the twelfth nerve; it is, therefore, appropriately called the **eminentia hypoglossi** (Streeter). The entire hypoglossal nucleus, however, is of much larger size (about 12 mm. long by 2 mm. wide) and extends some 5 mm. below the tip of the calamus scriptorius, ventral (anterior) to the

FIG. 949.



Floor of the fourth ventricle; areas corresponding to nuclei of nerves are shown on right half of figure. × $\frac{3}{2}$. (*Streeter.*)

vagus nucleus and nucleus gracilis. Lying immediately above the hypoglossal eminence is a second and somewhat less pronounced elevation, formed by the nucleus funiculi teretis and measuring nearly 6 mm. in length by 1 mm. in breadth. Lateral to these two median elevations and limited externally by the ala cinerea, lies a wedge-shaped field that is insinuated between the hypoglossal eminence and the vagal trigone. It stretches from the acoustic striæ above to the nib of the calamus scriptorius below. This field, named the *area plumiformis* by Retzius on account of its feather-like markings, is regarded by Streeter as corresponding to a group of cells, the **nucleus intercalatus**, that occupies a superficial position in the ventricular floor and partly overlies the hypoglossal nucleus.

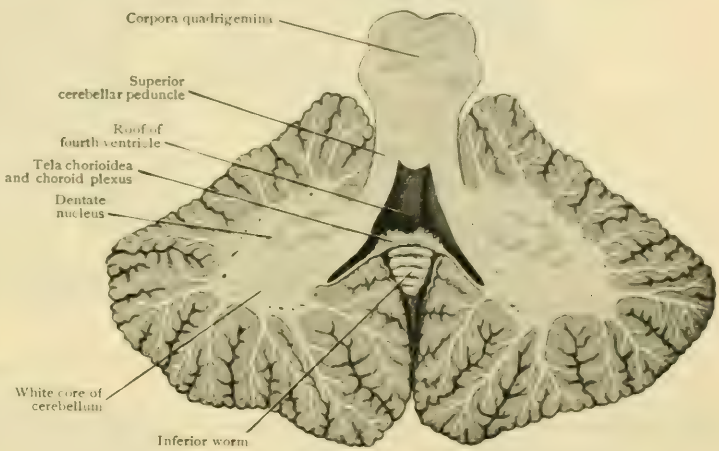
The **fovea vagi** (ala cinerea), which lies lateral to the nucleus intercalatus, corresponds to the middle and superficial third of the vago-glosso-pharyngeal nucleus, the entire extent of the latter including a tract measuring about 13 mm. in length by 2 mm. in breadth, that stretches from beneath the vestibular nucleus above to over 2 mm. beyond the inferior angle of the ventricle. The lower third of the area of the vagus nucleus is partly within the ventricle; immediately above the obex this intraventricular portion is covered by a layer of loose vascular tissue and appears as an upwardly diverging pointed field, **area postrema** of Retzius. This is separated from the ala cinerea by a translucent ridge, the **funiculus separans**, composed of thickened ependymal neuroglia (Streeter).

[1] Das Menschenhirn, 1896.
[2] Amer. Journal of Anat. Vol. II, 1903.

The prominence of the eminentia teres is due to the underlying nucleus of the sixth nerve, enclosed by the knee of the facial ; for it, therefore, Streeter proposes the name **eminentia abducentis.** The longitudinal ridge that continues upward and bounds the median fovea, the last cited author interprets as due to a field of gray matter, thin in the vicinity of the abducent eminence and thicker above, to which the name **nucleus incertus** is applied. Lateral to the nucleus incertus and the facio-abducent eminence, lies the fovea anterior, which elongated and depressed area (nearly 6 mm. long by 1 mm. wide) is due to the exit of the root of the fifth nerve ; it may, therefore, be called the **fovea trigemini.** The median portion of the elevated acoustic area includes the elongated and irregularly lozenge-shaped **vestibular area,** that measures about 16 mm. in length by 4 mm. in breadth and extends from the fovea anterior (trigemini) to the nucleus gracilis. The lateral part of the area acustica is occupied by the **cochlear area,** which stretches into the recessus lateralis and overlies the **nucleus cochlearis.**

The Roof of the Fourth Ventricle.—Viewed in median sagittal section (Fig. 938), the roof of the fourth ventricle appears as a tent-like structure, whose walls, where they come together, bound a space, the **recessus tecti,** that penetrates the cerebellar medulla between the superior and inferior worm. The upper wall of the tent is formed by the **superior medullary velum,** the triangular sheet of white matter stretching from beneath the quadrigeminal bodies above to the medullary substance of the cerebellum below, and is overlaid by the rudimentary cerebellar folia of the lingula. It must be understood that the ventricular surface of the velum is clothed by the ependyma—as are all other parts not only of the fourth ventricle but of all the ventricular cavities. Laterally the superior medullary velum is attached to the superior cerebellar peduncles, which to a limited extent share in closing in this part of the ventricle (Fig. 936).

FIG. 950.



Dorsal portion of preparation shown in Fig. 948; roof of fourth ventricle is seen from below.

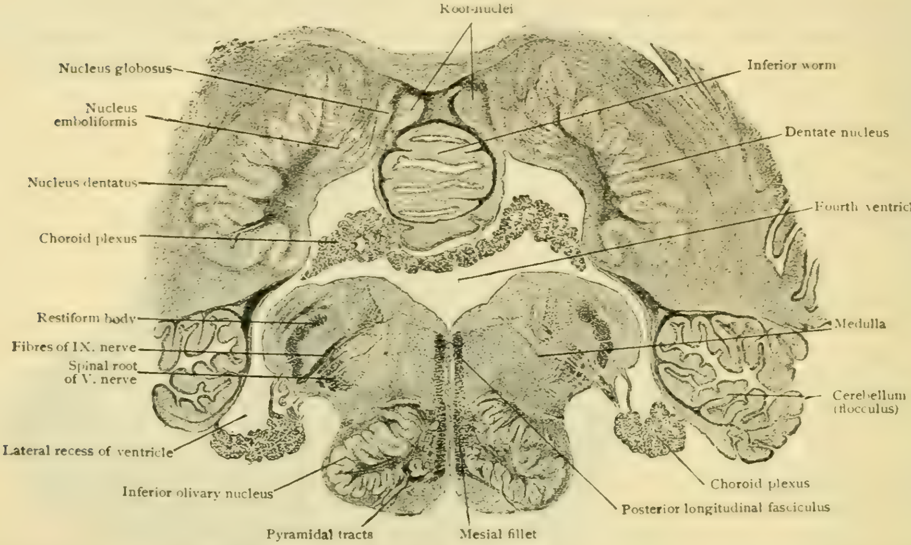
The lower half of the roof comprises two parts, an upper and thicker crescentic plate of white matter, the *inferior medullary velum,* and a lower and extremely thin membrane, the *tela chorioidea.* Medially the **inferior medullary velum** is attached for some distance to the front and lower surface of the nodule, which it excludes, strictly regarded, from the ventricle, whilst laterally the velum is prolonged to the flocculus, its fibres becoming continuous with the white core of this subdivision of the cerebellum. The nervous constituents of the velum extend only as far as its crescentic lower border, beyond which the roof of the ventricle, in a morphological sense, is formed by the ependymal layer alone. This, however, is supported by a backing of pial tissue, which, in conjunction with the ependyma, forms the **tela chorioidea.** On nearing the lower angle of the ventricle, the roof presents a triangular thickening, the **obex,** that closes the cleft between the clavæ and lies behind (above) the nib of the calamus scriptorius.

On each side the obex, which consists of a layer of white matter fused with the underlying ependyma, is continuous with the slightly thickened margin of the roof, the **tænia ventriculi,** whose line of attachment passes from the clava upward and outward over the cuneate tubercle of the medulla and the restiform body and, farther upward, runs obliquely across the dorsal surface of this peduncle to close in the **lateral**

recess—one of the pair of diverticula that overlie the inferior cerebellar peduncles and add materially to the transverse dimension of the ventricle. After enclosing the lateral recess the tænia leads to the stalk of the flocculus and the inferior velum.

Within the triangular field of the tænia chorioidea, the pia mater takes advantage of the attenuation of the ventricular wall to effect invaginations by which its blood-vessels apparently gain entrance into the ventricle. Such invaginations, known as the **choroid plexus of the fourth ventricle,** occur in the ventricular roof on each side and in the immediate vicinity of the mid-line, where they appear as parallel villous or fringe-like stripes, the **median plexus,** which extends upward from near the obex to the inferior medullary velum. Opposite the nodulus they

FIG. 951.



Section across lower third of fourth ventricle, showing internal cerebellar nuclei, choroid plexus, lateral recesses and medulla; new-born child. × 3⅓. Preparation by Professor Spiller.

diverge and, as the **lateral plexuses,** invaginate the wall of the lateral recesses. The vascular complex lies within the fold of pial tissue, the space between the pial layers being occupied by prolongations of the arachnoid.

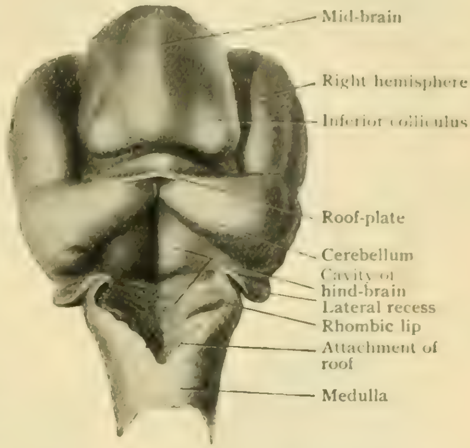
Notwithstanding its conspicuous thinness during the first half of fœtal life, the tela chorioidea suffices to completely close the ventricle. From about the fifth month, however, the delicate membrane is perforated by an aperture that remains throughout life. This opening, the **foramen of Magendie** (**apertura medialis ventriculi quarti**) lies immediately above the obex and between the strands of the choroid plexus. Two additional clefts, the **foramina of Luschka** (**aperturae laterales**), usually exist, one on each side, in the wall of the lateral recesses in the neighborhood of the vago-glosso-pharyngeal nerves. By means of these three openings, and probably by these alone, the system of ventricular cavities and the central canal of the spinal cord are brought into communication with the subarachnoid lymph-space. A path is thus provided by which the cerebro-spinal fluid, secreted within the lateral, third and fourth ventricles by the various choroid plexuses, constantly escapes and thereby prevents undue accumulation and distension within the cavities of the brain and spinal cord.

THE DEVELOPMENT OF THE HIND-BRAIN DERIVATIVES.

In the general sketch of the development of the brain previously given (page 1061), it was pointed out that the hind-brain, or *rhombencephalon*, includes two subdivisions, the *myelencephalon* and the *metencephalon*, the extreme upper part of the latter being designated the *isthmus*. It has been further noticed that the junction of the cord and brain-segments of the neural tube corresponds with the conspicuous cervical flexure, whose early appearance is followed by an

outward bending of the lateral walls of the brain-vesicle and the stretching and flattening of the roof-plate. In consequence of these changes the root of the rhombencephalon becomes reduced to an attenuated sheet which, when viewed from above, appears as a lozenge-shaped membrane that closes in the subjacent cavity, the subsequent fourth ventricle. It has also been pointed out (page 1049) that the relatively thick lateral walls of the neural tube exhibit, even within the cord-segment, a differentiation into a *dorsal* and a *ventral zone* (the alar and basal laminæ of His), which subdivisions are associated with the sensory and motor root-fibres of the nerves respectively. Similar relations, in a more pronounced degree, are evident within the brain-stem and are of much interest as indicating the morphological correspondence of the purely motor nerves (the third, fourth, sixth and twelfth) on the one hand, and of the mixed nerves (the fifth, seventh, ninth and tenth) on the other.

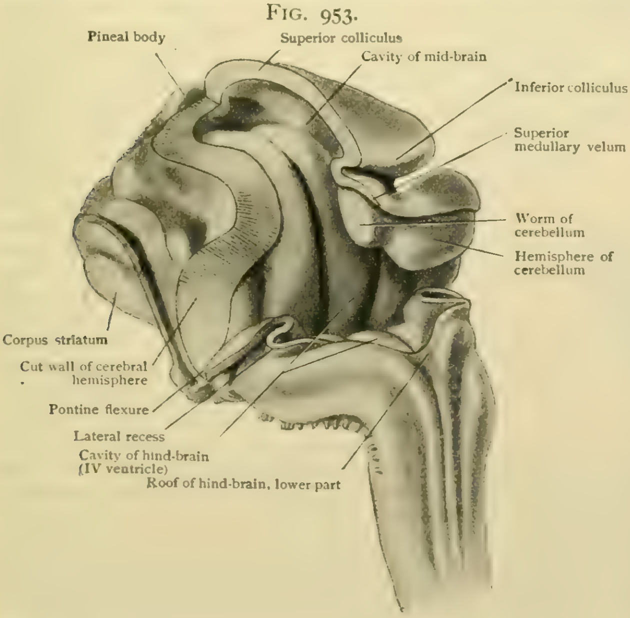
FIG. 952.



Reconstruction of brain of human embryo of 22.8 mm., showing hind-brain and part of mid-brain viewed from behind. × 12. Drawn from model made by Dr. Ewing Taylor.

The Medulla.—The great preponderance of the nervous matter along the floor of the fourth ventricle, as represented by the medulla, is due primarily to the outward bending of the lateral walls of the myelencephalon, supplemented by the accession of large tracts of nerve-fibres that later grow in from other parts of the cerebro-spinal axis. In consequence of the former change, the dorsal zones of the side-walls are gradually displaced laterally; at the same time they become partly folded on themselves to produce along their outer margin the *rhombic lip* (His), which is directly continuous with the expanded and thin roof-plate. Later, the dorsal zones come to lie almost horizontally, their ventricular surface corresponding with that of the ventral laminæ, in conjunction with which the floor of the definitive fourth ventricle is later formed. Coincidently with the outward migration of the dorsal laminæ, the ventral zones also thicken and assume a much more horizontal position, with their inner ends separated superficially by a median furrow and, deeper, by the compressed remains of the floor-plate. Very early and before the flattening out of the myelencephalon has advanced to any marked extent, the demarcation between the dorsal and ventral zones is evident as a lateral longitudinal groove on the ventricular surface of the myelencephalon. Indications of this division persist and in the adult medulla are represented by the fovea inferior and the sulcus lateralis seen on the floor of the fourth ventricle. As in the cord-segment, so in the myelencephalon the lateral walls are the only regions of the neural tube in which neuroblasts are developed, the roof-plate and the floor-plate containing spongioblasts alone.

FIG. 953.

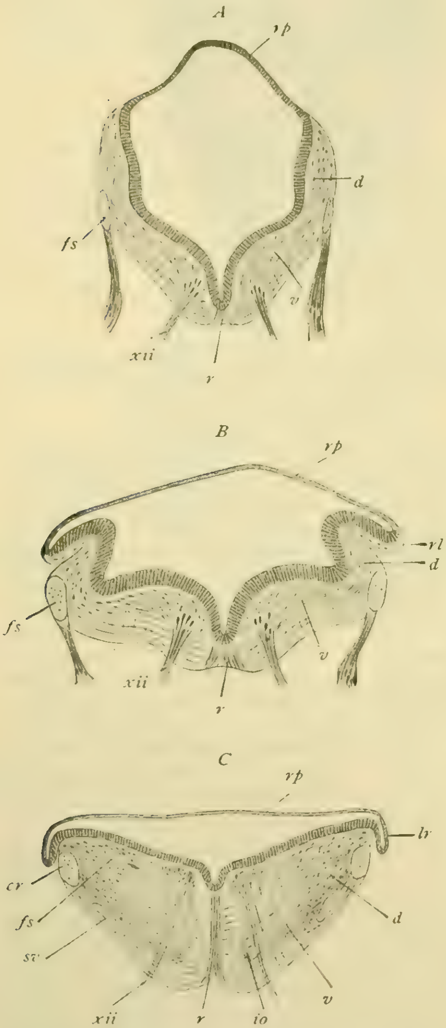


Reconstruction of hind-brain of human embryo of about three months (50 mm.), viewed from side and behind. Drawn from His model.

Very early and before the flattening out of the myelencephalon has advanced to any marked extent, within the ventral zones and close to the mid-line, appear groups of neuroblasts, from which axones grow ventrally to form the root-fibres of the motor (hypoglossal) nerves. Sensory

fibres are also early represented by bundles which grow centrally from the ganglion of the vagus towards the developing medulla, upon whose surface, opposite the junction of the dorsal and ventral zones, they appear as a flattened oval bundle (fasciculus solitarius). For a time superficial and loosely applied, this bundle gradually becomes more deeply placed in consequence of the extension, ventral folding, and final fusion of the rhombic lip with the remainder of the dorsal zone. Subsequently the fasciculus solitarius becomes still farther removed from the surface by the ingrowth of tracts of nerve-fibres from the neuroblasts of the rhombic lip and from other sources until, finally, the bundle comes to lie beneath the ventricular floor where its position permanently indicates the junction between the original dorsal and ventral zones of the medullary wall. In a similar manner the sensory fibres of the trigeminal nerve are applied to the surface of the developing pons; since, however, the bundle is attached after consolidation of the dorsal zone of the medulla has begun, the descending trifacial fibres retain the relatively superficial position characterizing the spinal root, while the descending root (fasciculus solitarius) of the glosso-pharyngeo-vagus lies more deeply placed. Subsequent to the invasion of the medulla by the sensory parts of this nerve, the outgrowth of the axones from the neuroblasts constituting the nucleus of origin provides its motor root-fibres.

FIG. 954.



Transverse sections of hind-brain of human embryos, showing three stages in development of medulla; *A*, about four and a half weeks; *B*, about six weeks; *C*, about eight weeks; *rp*, roof-plate; *r*, raphe; *d*, *v*, dorsal (alar) and ventral (basal) laminæ; *rl*, rhombic lip; *lr*, lateral recess; *fs*, fasciculus solitarius; *cr*, restiform body; *xii*, hypoglossal nerve; *sv*, spinal root of trigeminus; *io*, inferior olivary nucleus. (*His*.)

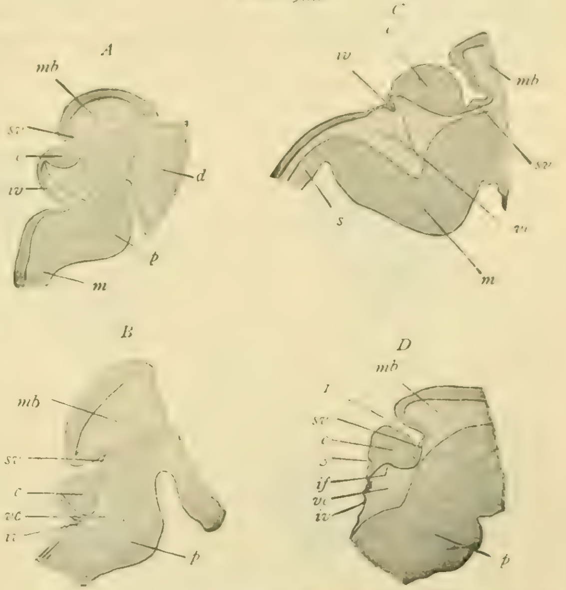
The rhombic lip is a region of much importance, since from the neuroblasts which appear within it are derived the cells of the reception nuclei (substantia gelatinosa) of the sensory cranial nerves, of the nuclei of the posterior columns, of the inferior and accessory olivary nuclei and of the arcuate nucleus. From the neuroblasts many axones grow medio-ventrally, pierce the median spongioblastic septum derived from the primary floor-plate, which later becomes the median raphe, and gain the opposite side and thus establish the systems of arcuate fibres. Other axones grow dorsally and take part in eventually producing the fibre-tracts connecting the olivary, dorsal and arcuate nuclei with the cerebellum. It is evident that the development of the myelencephalon primarily contributes the nervous substance that becomes the dorsal part of the medulla and underlies the fourth ventricle. Later the closed part of the medulla, which at first is wanting, as well as the conspicuous pyramidal tracts, are added as the strands of ascending and descending fibres grow into the medulla from the spinal cord and from other parts of the brain. In this manner the important tracts of the posterior columns and the spinal constituents of the restiform body and of the brain-stem are added and, still later, the bulky pyramids take form when the cerebro-spinal paths are established.

In accord with the falling apart and thickening that affect the lateral walls of the myelencephalon and lead to the production of the medulla, the roof-plate of the brain-vesicle becomes flattened and laterally expanded to keep pace with the increasing width of the ventricular floor. In consequence, the roof-plate is converted into a rhomboidal sheet of great delicacy, the *primary velum*, which histologically consists of little more than the layer of ependymal cells. These, however, soon come into close relation with the overlying mesoblastic tissue from which the pia is differentiated. During the third month a transverse fold, the *plica chorioidea*, appears in the roof-sheet, near the posterior limit of the developing cerebellum (Fig. 955, *B*). Into this

duplicature, directed towards the brain cavity, the mesoblast grows and later develops blood-vessels, and is converted into a vascular complex that eventually forms the *choroid plexus* of the fourth ventricle. From the manner of its development, it is evident that the plexus is excluded by the ependymal layer from the ventricular space, outside of which the pial blood-vessels, therefore, really lie. The conversion of the upper part of the primary velum into the thicker definite *inferior medullary velum* follows the addition of nervous substance during the development of the cerebellum. Similar thickening of the roof-sheet at the lower angle of the ventricle results in the production of the obex and the tæniæ.

The Pons.—The pons arises as a thickening of that part of the metencephalon which forms the anterior wall of the pontine flexure. In its essential phases the development of the pons probably closely resembles that of the medulla, since the early metencephalon presents the same general features as does the myelencephalon. Thus, the ventral zones of its lateral walls play an active rôle in the production of the tegmental portion of the pons and the nuclei of origin of the motor root-fibres of the fifth, sixth and seventh nerves, whilst the floor-plate becomes the raphe. In addition to providing the reception-nuclei of the sensory cranial nerves, and, perhaps, the pontine nuclei, the dorsal zones contribute the neuroblasts which become the nervous elements of the cerebellum. As in the medulla, so in the pons the great ventral tracts are secondary and relatively late additions to the tegmentum, which must be regarded as the primary and oldest part of this segment of the brain-stem, the bulky ventral nervous masses taking form only after the appearance of the cerebro-spinal and cerebro-cerebellar paths. In a manner analagous to that by which the sensory part of the vagus is at first loosely applied and later incorporated with the medulla, the sensory fibres of the trigeminus are for a time attached to the surface of the dorsal zone of the pons, subsequently becoming covered in and more deeply placed by the addition of peripheral tracts. Likewise the fibres of the auditory nerve come into relation with the superficially situated reception-nuclei of the cochlear and vestibular nerves.

FIG. 955.



Median sagittal sections showing four early stages of development of human cerebellum, from fœtuses from 5 to 9 cm. long; *mb*, mid-brain; *c*, cerebellum; *sv*, *iv*, superior and inferior medullary velum; *vc*, ventricular cavity; *d*, cavity of diencephalon; *p*, pons; *m*, medulla; *s*, spinal cord; *if*, incisura fastigii; *1*, sulcus primarius; *3*, sulcus postnodularis. (*Drawn from figures of Bolk.*)

The Cerebellum.—The development of the human cerebellum proceeds from the roof-plate and adjacent parts of the dorsal zones of the lateral walls of the metencephalon. In an embryo 22.8 mm. long, the cerebellar anlage consists of two lateral plates connected by a narrow thin intervening lamina representing the roof-plate (Fig. 952). After the apposition of the lateral plates, which soon occurs, this bridge disappears, the developing cerebellum for a time appearing as an arched lamina enclosing the upper part of the cavity of the hind-brain (Kuithan[1]).

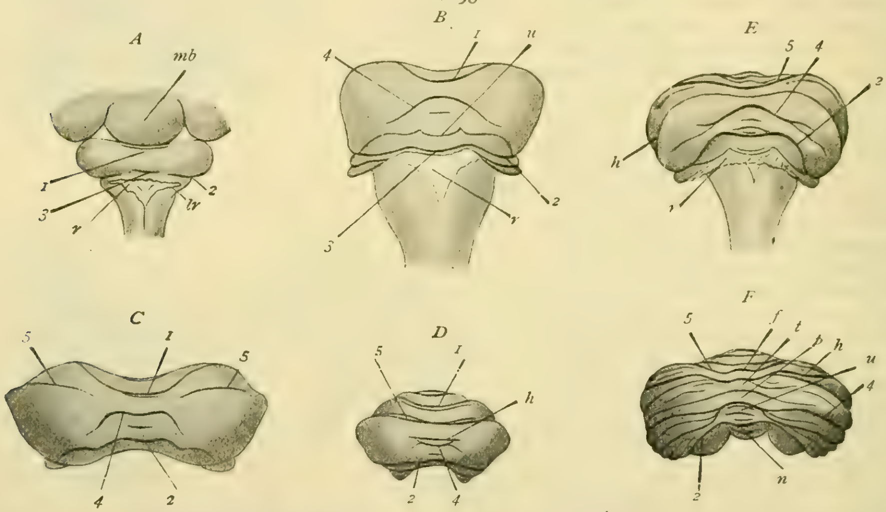
The subsequent development of the human cerebellum has been recently carefully studied by Bolk[2] in a series of about forty fœtuses, hardened in formalin and ranging from 5 to 30 cm. in their entire (crown-sole) length. The following account is based largely on these investigations. In a fœtus of 5 cm., about nine weeks old, the cerebellar anlage is represented by a horseshoe-shaped thickening of the metencephalic roof, the *cerebellar lamina*, whose upper margin is connected by a conspicuous fold with the mid-brain and whose lower border has attached to it the *primary velum*—the thin rhomboidal roof-plate of the myelencephalon. Median sagittal section of the cerebellar lamina at this stage (Fig. 955, *A*) shows its form to be asymmetrically biconvex, the more convex surface encroaching upon the brain-cavity. In a slightly older fœtus (Fig. 955, *B*) the cerebellar lamina has become triangular, in section presenting a superior, an anterior, and an inferior surface. From its attachment along the superior margin of the lamina the inferior velum dips forward toward the pontine flexure and, forming a transversely cresentic

[1] Münchner med. Abhand., 1895.
[2] Petrus Camper, 3e Deel, 1905.

fold, the *plica chorioidea*, bounds a narrow recess that extends along the inferior surface of the cerebellar lamina. This recess is only temporary and is soon obliterated by the subsequent attachment of the roof-membrane to the inferior surface of the cerebellar lamina. The succeeding stage (Fig. 955, *C*) emphasizes the alteration in the planes of the cerebellar surfaces, the former superior now becoming the anterior, the anterior the inferior, and the inferior the posterior. From the posterior margin of the dorsal surface the choroid fold dips into the brain-cavity. Between the mid-brain and the cerebellum now stretches the first definite indication of the later superior medullary velum. In agreement with His, Bolk recognizes that the former intraventricular (inferior) surface has now become an extraventricular one and that the permanent attachment of the plica chorioidea corresponds to a secondary and not to the primary line of union.

The stage represented in Fig. 955, *D* is important, since it marks the beginning of the first fissures. One of these, the *sulcus primarius* (the *fissura prima* of Elliot Smith), appears as a transverse groove on the upper part of the anterior surface and thus early establishes the fundamental division of the cerebellum into an anterior and a posterior lobe. The other fissure appears in the median area near the posterior margin of the cerebellum and is the *sulcus postnodularis.* On each side (Fig. 956, *A*) an additional fissure cuts off a narrow tract that embraces the postero-lateral area of the cerebellum. This fissure, the *sulcus flocculáris*, for a time remains ununited with the postnodular sulcus ; but later, with its fellow, it becomes continuous with the postnodular sulcus and thus defines a narrow band-like tract, the median part of which

FIG. 956.



Six stages in development of human cerebellum, from fœtuses of 9 (*A*), 13 (*B*), 15 (*C*), 22 (*D*), 25 (*E*), and 32 cm. (*F*) length; *1*, sulcus primarius (preclival); *2*, s. flocculáris; *3*, s. postnodularis; *4*, s. infrapyramidalis; *5*, s. superior posterior (postclival); *h*, great horizontal fissure; *mb*, mid-brain; *r*, roof-membrane; *lr*, lateral recess; *n*, nodulus; *u*, uvula; *p*, pyramis; *t*, tuber; *f*, folum. (*Drawn from figures of Bolk.*)

eventually becomes the nodule, the lateral portions the flocculi, whilst the intervening strips become the floccular peduncles and part of the inferior medullary velum. The diverticulum bounded on each side by the floccular area is the beginning of the lateral recess of the fourth ventricle and is early filled by the rapidly growing choroid plexus. A shallow transverse groove, the *incisura fastigii*, just suggested in Fig. 955, *C* but distinct in the succeeding sketch, marks the beginning of the tent-like recess that later conspicuously models the roof of the fourth ventricle. Coincidently with and about midway between the fissures just described, a third furrow appears on the posterior cerebellar lobe. This is the *fissura secunda* (Elliot Smith) or the *infrapyramidal sulcus.* Very shortly a fourth groove appears behind the sulcus primarius and marks the beginning of the *prepyramidal* fissure. In this manner the median tract of the posterior lobe is early subdivided by three fissures into four areas, which, from behind toward the sulcus primarius, give rise to the nodule, the uvula, the pyramid and a still undifferentiated zone. By the subsequent appearance of additional furrows, this narrow zone gives origin to the tuber, the folium cacuminis and the clivus. Meanwhile on the anterior lobe of the cerebellum three short transverse fissures appear, by which the anterior end of the worm-tract is broken up into areas that, while establishing subdivisions of morphological value (Bolk), are later lost in the uncertain foliation of the lingula and lobulus centralis of the mature cerebellum.

After the fundamental subdivision of the median area (worm) has been accomplished, the lateral masses (hemispheres) of the cerebellum become subdivided into definite tracts (lobules) by fissures that appear during the fourth and fifth months of fœtal life. The lateral extensions

of the sulcus primarius—itself the later *preclival fissure*—separate the anterior and posterior crescentic lobules. During the fourth month the *postlunate fissure* appears, in each hemisphere, on the upper surface of the posterior lobe. By the extension and medial union of these sulci, for a time separate, are established the posterior limit of the clivus (*postclival fissure*) and the demarcation between the posterior crescentic and the postero-superior lobule. The *post-tonsillar fissure* bounds the conspicuous elevation of the tonsil behind and medially joins the infrapyramidal (later prepyramidal) sulcus. The *parapyramidal fissure* defines the upper (posterior) limit of the biventral lobule and unites with the suprapyramidal (later postpyramidal) fissure. The *great horizontal fissure*, so conspicuous in the mature cerebellum, appears relatively late, about the end of the fifth month, and is at first represented by a shallow transverse median furrow that lies immediately in front of the suprapyramidal fissure (Bolk), an origin at variance with the generally accepted formation of the horizontal fissure by the union of two lateral sulci, that grow medially from the hemispheres and meet in the worm. The early fissure having such history, Bolk identifies as the postlunate (sulcus superior posterior) and not as the horizontal. This author also emphasizes the fact that at the sixth fœtal month the folium cacuminis is, as a rule, not only defined, but forms a well-marked superficial tract that connects the adjoining lateral tracts (postero-superior lobules). This part of the worm, however, does not keep pace with the cortical expansion of the surrounding parts and, hence, becomes overgrown by these and sinks into the relative insignificance that distinguishes this part of the worm in the fully matured cerebellum. In consequence of the rapid growth and expansion of the peripheral portions of the human cerebellum, some fissures of secondary morphological importance, as the horizontal, become excessively deepened and more conspicuous in man than those of fundamental significance, as the sulcus primarius (preclival) and the postnodular fissures. This cortical expansion, especially within the superior region, likewise brings about prominent changes in the position of the segments of the worm, so that eventually those which primarily lay behind later come to lie below, the divisions of the conventional upper and lower worm of the mature cerebellum following along the C-like curve seen in sagittal sections.

The **histogenesis of the cerebellar cortex** probably primarily proceeds from the invasion of the cellular lamina by the cells of the dorsal zones of the lateral walls of the metencephalon, as well as directly from these zones themselves. The earliest differentiation results in the production of three strata: (*a*) the inner *ependymal layer*, and (*b*) the middle *mantle layer*, and (*c*) the outer *marginal layer*. Of these the mantle layer is the thickest and richest in cells, from which both neuroblasts and spongioblasts arise, although their differentiation occurs relatively late. The *Purkinje cells*, early distinguishable by their large clear nuclei, appear during the sixth fœtal month, but for some time lack their characteristic processes. Likewise from the mantle layer are derived the earliest constituents of the *granule layer*. Meanwhile within the marginal layer, immediately beneath the external surface of the cerebellum, an additional and temporarily conspicuous cell-stratum, the *external granule layer*, becomes a prominent feature of the developing cerebellar cortex. This layer soon exhibits a subdivision into two zones of which the outer contains many dividing cells, while the inner is almost free from karyokinetic figures. During the later months of fœtal life the inner sublayer disappears and at birth the outer one is greatly reduced; finally, this also disappears, so that after the earliest years of childhood the external granule layer is no longer seen. The chief factor in this reduction and eventual obliteration of this stratum is, according to Cajal, the gradual transformation of its neuroblasts into nerve-cells that recede from their peripheral position to assist in the completion of the granule layer, as whose small and characteristically branched elements they persist. Other neurones of the external granule layer are transformed into the *basket cells* and the large *stellate cells*. The *neuroglia* of the cerebellar cortex is derived chiefly from the spongioblastic elements of the inner or ependymal layer, the conversion of the cells of the outer granule layer into the supporting tissue, as sometimes assumed, being unlikely (Ziehen). Since the molecular layer is composed to a considerable extent of the dendritic processes of the Purkinje cells, the development of the outer division of the cerebellar cortex is complete only after the growth of such processes, as well as of the climbing fibres from the white core, has taken place.

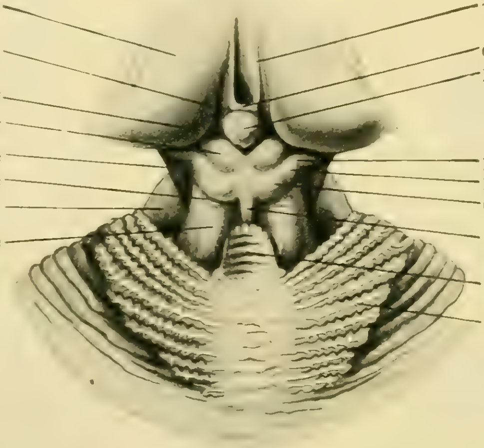
The production of the *superior cerebellar peduncles* and of the definite *superior medullary velum* is dependent upon the development of the fibres that pass from and to the dentate nucleus and the cerebellar cortex—an invasion that occurs during late fœtal and early post-natal life.

THE MESENCEPHALON.

Notwithstanding its considerable size and prominent position in the embryo, in its mature condition the mesencephalon, or mid-brain, forms the smallest and least conspicuous division not only of the brain-stem but also of the entire brain. Nevertheless, the many fundamental tracts which it contains, as well as the new paths and combinations which arise within its substance, confer on the mid-brain an importance

not suggested by its size. Its upper limit corresponds with an oblique plane passing through the base of the pineal body and the posterior border of the corpora mammillaria; its lower one is indicated on the ventral surface by the upper border of the pons and on the dorsal aspect by the upper margin of the superior medullary velum. As seen in sagittal sections (Fig. 938,) the mid-brain is about 11 mm. in length, although when measured on the ventral surface it is slightly shorter (9 mm.) and on the dorsal aspect a little longer (13 mm.). Its greatest breadth is approximately 23 mm. The mid-brain is traversed longitudinally by a canal, the *Sylvian aqueduct*, which, however, lies much nearer the dorsal than the ventral surface of the brain-stem. When the several parts of the brain are undisturbed, only a portion of the ventral aspect of the mid-brain can be seen. Its dorsal and lateral surfaces are hidden by the overhanging cerebral hemispheres, the splenium of the corpus callosum and the pulvinar of the thalamus being in close relation with these surfaces respectively. Notwithstanding its ventral position and apparent removal from the exterior of the brain behind, the dorsal surface of the mid-brain is, in fact, directly continuous with

FIG. 957.



Mid-brain viewed from behind; upper part of cerebellum has been removed to expose superior medullary velum with lingula.

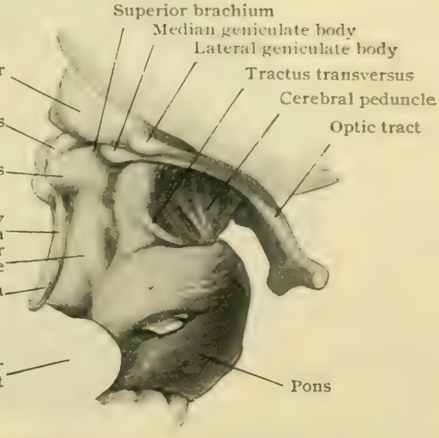
and a part of the free posterior surface of the brain. It is, therefore, covered with the pia mater, as may be demonstrated by drawing aside the overhanging cerebral hemispheres. *In situ* the mid-brain occupies the opening bounded by the tentorium and thus connects the divisions of the brain which lie within the posterior cranial fossa (cerebellum, pons and medulla) with those (cerebral hemispheres) that lie above. Its cavity, the Sylvian aqueduct, establishes direct communication between the third and fourth ventricles. The mid-brain includes two main subdivisions, a smaller dorsal part, the *quadrigeminal plate*, which roofs in the Sylvian aqueduct and bears the corpora quadrigemina, and a much larger ventral part, made up by the *cerebral peduncles.*

The **quadrigeminal plate** lies behind the plane of the roof of the Sylvian aqueduct and extends from the base of the pineal body above to the upper margin of the anterior medullary velum below. Its dorsal surface is subdivided into four white rounded elevations, the **corpora quadrigemina,** by two grooves, one of which is a median longitudinal furrow and the other a transverse furrow that crosses the first one at right angles and slightly below its middle point. The upper part of the longitudinal groove, between the upper pair of elevations, broadens into a shallow triangular depression, the **pineal fossa** (**trigonum subpineale**) in which rests the pineal body. Below, the mid-furrow ends at the base of the frenum of the superior medullary velum.

The elevations forming the upper pair of quadrigeminal bodies, the **colliculi superiores,** are the larger and more conspicuous, and measure from 7–8 mm. in length, about 10 mm. in breadth, and 6 mm. in height. Laterally each superior colliculus is continued into an arm, the **superior brachium** (**brachium quadrigeminum superius**) which is defined by a groove above and below, and passes upward and outward, between the optic thalamus and the median geniculate body, to be lost within an indistinctly circumscribed oval eminence, the **lateral geniculate body** (**corpus geniculatum laterale**), which lies beneath the pulvinar. In like manner, each of the smaller lower pair of quadrigeminal bodies, the **colliculi inferiores,** (about 6 mm. in length by 8 mm. in breadth and 5 mm. in height) is prolonged laterally into the **inferior brachium** (**brachium quadrigeminum inferius**), which in turn ends in the sharply defined **median geniculate body** (**corpus geniculatum mediale**), an oval elevation about 10 mm. in length. Ventrally the quadrigeminal plate becomes directly continuous with the adjacent part of the cerebral peduncles.

The **cerebral peduncles** (**pedunculi cerebri**), also called the *cerebral crura*, constitute the bulky ventral part of the mid-brain. Dorsally, the two peduncles are fused into a continuous tract, the **tegmentum**, which contributes the side-walls and floor of the Sylvian aqueduct and blends on each side with the overlying quadrigeminal plate. Ventrally the peduncles are unfused and appear on the inferior surface of the brain as two robust stalks (Fig. 993). These emerge from the upper border of the pons and pass, diverging at an angle of from 70–85°, upward and outward to enter, one on each side, the cerebral hemispheres just where the peduncles are crossed by the outwardly winding optic tracts. At the pons each peduncle possesses a breadth of from 12–15 mm., which increases to from 18–20 mm. at the upper end of the stalk ; the borders of each peduncle are, therefore, not quite parallel, but slightly diverging. Neither are the mesial margins of the peduncles in contact as they issue from the pons, but separated by an interval of about 3 mm. This distance increases until at their upper ends the peduncles are about 13 mm. apart.

FIG. 958.



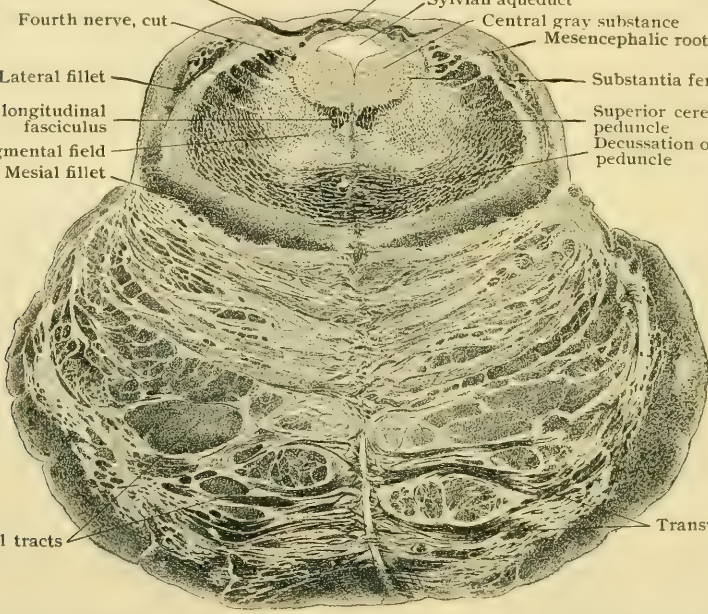
Dorso-lateral aspect of mid-brain.

Superficially each peduncle is formed by strands of fibres which do not pursue a strictly longitudinal course, but wind spirally from within outward ; in consequence of this arrangement the surface of the peduncle presents a characteristic twisted or rope-like striation. The regularity of this marking is sometimes disturbed by a faintly defined strand of fibres (**tractus peduncularis transversus**), that winds over the median border and ventral surface of the peduncle, passes upward and outward across the lateral surface of the mid-brain, to be lost in the vicinity of the medial geniculate body. The depressed triangular area included between the diverging peduncles is the **interpeduncular fossa,** the floor of which is pierced by numerous minute openings that transmit small blood-vessels, and hence is known as the **posterior perforated substance.** The blunted inferior angle of the fossa, immediately above the pons, corresponds with a depression, the **recessus posterior**; another, but less marked depression, the **recessus anterior,** is bounded by the postero-median surfaces of the mammillary bodies. A shallow lateral groove (**sulcus mesencephali lateralis**) extends along the outer surface of the peduncle, whilst along its inner aspect, and therefore looking into the interpeduncular fossa, runs the median or **oculomotor groove** (**sulcus nervi oculomotorii**), that is more distinct than the lateral furrow and

marks the line along which the root-fibres of the third cranial nerve emerge. On transverse section (Fig. 963) these furrows are seen to correspond with the edges of a crescentic field of deeply pigmented gray matter, the **substantia nigra**, by which each peduncle is subdivided into a dorsal portion, the **tegmentum,** and a ventral part, the **crusta** (**basis pedunculi**). The latter lies ventral to the superficial lateral and median furrows, and contributes largely to the bulk of the free part of the peduncle. When traced upward it is found to enter the cerebral hemisphere and become continuous with the internal capsule. It contains the great motor tracts and is the chief pathway by which efferent cortical impulses are transmitted to the lower lying centres. The tegmentum, on the contrary, in a general way is associated with the sensory tracts, and, above, enters the subthalamic region (page 1127).

The **dorso-lateral surface** of the mid-brain, just where it passes into that of the superior cerebellar peduncle, shares with the latter a triangular area, the **trigo-**

FIG. 959.



Transverse section of brain-stem at level L (Fig. 919), junction of pons and mid-brain; superior cerebellar peduncles are beginning to decussate; trochlear decussation seen above Sylvian aqueduct. Weigert-Pal staining. × 3. Preparation by Professor Spiller.

num lemnisci, which, as implied by its name, is related to the underlying and here superficially placed tract of the fillet (lemniscus). Above, this area extends as far as the inferior brachium and is limited in front by the sulcus mesencephali lateralis, whilst behind it is defined from the superior cerebellar peduncle by a slight furrow (**sulcus limitans posterior**). When closely examined the triangular field is seen to be subdivided by a faint groove into an upper and a lower area, which correspond with the underlying fibres of the lateral and of the mesial fillet respectively. A superficial strand of fibres, the tractus peduncularis transversus, is sometimes seen crossing the lateral surface of the mid-brain. It appears on the dorsal aspect of the latter, between the inferior brachium and the median geniculate body, winds around the latero-ventral surface of the peduncle and disappears in the vicinity of the mammillary body. According to Marburg, the strand establishes a connection between the cells of the retina and a nucleus in the floor of the third ventricle and represents, in a rudimentary condition, the basic optic root found in many animals.

The **Sylvian aqueduct** (**aquaeductus cerebri**) represents the cavity of the middle brain-vesicle and, therefore, is lined with an ependymal layer continuous above and below with that clothing the interior of the third and fourth ventricles. As seen in

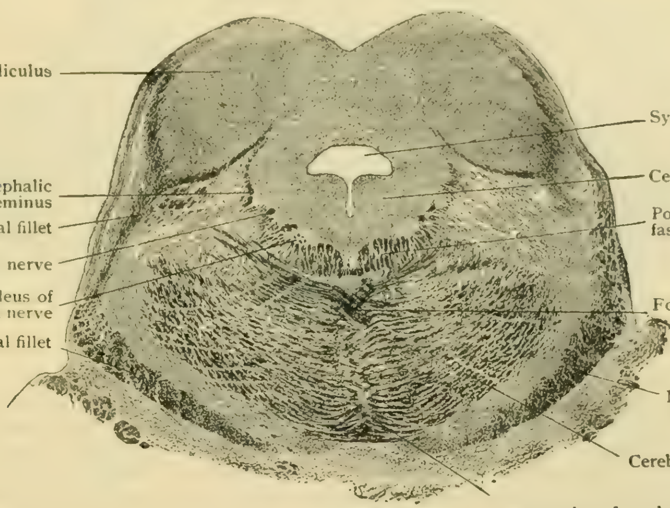
cross-sections, (Fig. 960) its outline in a general way is triangular, with the base above and the apex directly below; but the contour of the canal varies at different levels, being triangular near its extremities and irregularly cordiform or elliptical in the intervening part of its course.

INTERNAL STRUCTURE OF THE MESENCEPHALON.

Disregarding the several small nuclei, the nuclei of the corpora quadrigemina and the red nuclei, the gray matter within the mesencephalon is disposed as three tracts that extend the entire length of the mid-brain. These are the tubular mass of the *central gray matter*, which surrounds the aqueduct, and the two crescentic columns of the *substantia nigra*, which subdivide the peduncles into the tegmental and basal portions.

The **central gray matter** (**stratum griseum centrale**) completely encloses the cavity of the mid-brain and hence is often called the *Sylvian gray matter*. It contains numerous irregularly scattered nerve-cells of uncertain form and size, and, along its ventral border, the nuclei of origin of the oculomotor and trochlear nerves; within its lateral parts lie the nuclei from which proceed the fibres of the mesencephalic roots of the trigeminal nerves.

FIG. 960.



Transverse section of dorsal part of mid-brain through lower end of inferior colliculi, at level M (Fig. 919) showing nucleus of trochlear nerve, and decussation of cerebellar peduncle. Weigert-Pal staining. × 3½. Preparation by Professor Spiller.

The **substantia nigra** is disposed as two irregular crescentic columns of dark gray matter that separate the tegmentum from the crustæ of the peduncles. The substance begins below at the upper border of the pons and continues uninterruptedly through the length of the mid-brain into the subthalamic region of the diencephalon, where it gradually disappears. The deep color of this tract is due to the conspicuous pigmentation of its numerous nerve-cells. These cells are of medium size and of various form, spindle-shaped elements, interspersed with some of stellate and a few of pyramidal form, predominating. They enclose considerable accumulations of dark brown pigment that render the cells unusually conspicuous. During the earliest years of childhood the pigmentation is absent or very slight, but after the sixth year it is marked, and by the seventeenth has acquired its full intensity. Seen in cross-sections (Fig. 961), the convexity of each column, directed forward and outward, is not uniform, but broken into irregular scallops by processes of gray matter that penetrate the subjacent crusta. The concave dorsal margin, on the contrary, is unbroken and even. The horns of the crescentic areas, of which the median is somewhat the thicker, approach the free surface along the bottom of the superficial

lateral and median grooves of the mid-brain. Concerning the functions and connections of the neurones within the substantia nigra very little is known.

The Quadrigeminal and Geniculate Bodies.—The **inferior colliculus** consists chiefly of a biconvex (in section oval) mass of gray matter, the **nucleus colliculi inferioris,** in which many nerve-cells of varying form and mostly of small size lie embedded within a complex of nerve-fibres. The lower end of the nucleus stands in intimate relation with the acoustic fibres composing the lateral fillet, many of which enter the ventral aspect of the nucleus colliculi to end around its cells, whilst a considerable number pass superficial to the nucleus and thus form an external fibre-layer that intervenes between the gray nucleus and the surface. Although many of these external fillet-fibres enter the colliculus at higher levels, not a few continue, by way of the inferior brachium, to the median geniculate body, around whose neurones they end. A much smaller and less well defined tract of fillet-fibres passes to the mesial side of the nucleus, the ventral margin of which is thus embraced (Fig. 960) by the diverging but unequally robust fillet-strands that in this manner partially encapsulate the collicular nucleus. From the supero-lateral parts of the nucleus fibres proceed which, in conjunction with those continued from the lateral fillet, form the chief constituents of the **inferior brachium.** A part of this arm, however, is composed of strands of fibres that pass from the cerebral cortex (especially the temporal) to the inferior colliculus. Towards the upper pole of the nucleus some loose strands of fillet-fibres, probably along with commissural fibres uniting the inferior colliculi, cross the mid-line and establish a decussation.

The **internal** or **median geniculate body** (corpus geniculatum mediale), although genetically belonging to the diencephalon, is so closely related to the inferior colliculus as to require description in this place. It consists of a superficial layer of white matter composed of fibres from the inferior brachium, which pass outward as continuations of the lateral fillet, as axones of the cells of the inferior colliculus, or as fibres forming the mesial root of the optic tract, also known as the **inferior commissure of Gudden.** Within this fibre-capsule lies an oval mass of gray matter, the **nucleus corporis geniculati medialis,** from whose cells axones proceed chiefly towards the cerebral cortex in continuation of the auditory paths of which the inferior colliculus and the median geniculate body are important stations.

Connections of the Inferior Colliculus and Median Geniculate Body.—Mention has been made, when describing the reception-nuclei of the cochlear portion of the auditory nerve (page 1076), that the tract of the lateral fillet takes origin to an important extent from the cells of these nuclei, and, further, (page 1082), that the fillet-fibres end around either the cells of the inferior colliculus, or those of the median geniculate body. It is evident, therefore, that these parts of the mid-brain stand in intimate relation with the parts concerned in conveying auditory impulses. The more detailed account of the chaining together of the neurones forming such paths is deferred until the auditory nerve is considered (page 1257). The connection of the fibres composing the median root of the optic tract with the median geniculate body and the inferior colliculus has been established beyond doubt; further, that this part of the optic tract is not concerned in conducting visual impulses, is shown by the fact that these fibres remain unaffected under conditions (after removal of the eyes) that lead to degeneration of the fibres of retinal origin. The destination and significance of the fibre-systems included within the median root of the optic tract are only imperfectly understood, but it may be accepted as certain that they can no longer be regarded as merely establishing a bond between the median geniculate and indirectly the inferior quadrigeminal bodies of the two sides, as implied by the name commissure, since many of these fibres are probably directed after decussation to the lenticular nucleus (globus pallidus), while others possibly may end on the same side in the subthalamic nucleus (page 1128). The gray matter of the inferior colliculus, like that of the superior, gives rise to fibres of the tecto-bulbar and tecto-spinal tracts, presently to be described (page 1111).

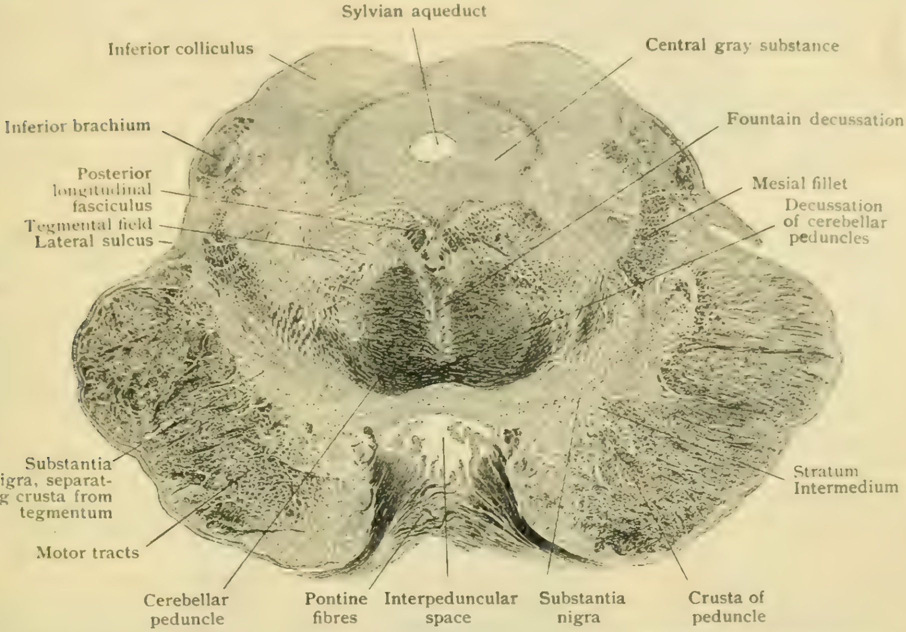
The **superior colliculus** is composed of a number of alternating layers of white and gray matter. The latter, however, is not aggregated into a definite nucleus, as in the case of the inferior colliculus, but is broken up into uncertain zones by the tracts of nerve-fibres. Although as many as seven layers have been described, some of these are so blended that only four well-defined strata can be readily distinguished. From the surface inward these are:

1. The **stratum zonale,** a thin peripheral fibre-layer that occupies the surface of the colliculus, whose components are fibres derived, in great part at least, from the optic tract.

2. The **stratum cinereum,** which is not uniform, but thickest and most marked over the convexity of the colliculus, and appears, therefore, crescentic in transverse sections. The nerve-cells contained in this cap-like sheet are small and relatively few, their axones passing for the most part towards the deeper layers, whilst their dendrites are directed peripherally. The stratum is by no means composed entirely of gray matter, but is invaded by many medullated nerve-fibres.

3. The **stratum opticum,** which consists of a complex of gray matter and nerve-fibres, the latter including strands derived from the optic tract, which gain the side of the colliculus by way of the superior brachium (page 1107) as direct continuations of the optic fibres, or after interruption in the lateral geniculate body. That this stratum includes other fibres, is shown by the incomplete involvement of the layer in conditions producing degeneration of the optic paths, as well as by the prominence of parts of the stratum in animals possessing only rudimentary visual paths (Edinger). The stratum opticum, however, consists by no means exclusively of fibres, but contains, especially in its deeper part, numerous nerve-cells of large size, around which the end-arborizations of the optic fibres terminate.

FIG. 961.



Transverse section of mid-brain at level N (Fig. 919); decussation of cerebellar peduncles is just ending. Weigert-Pal staining. × 3. Preparation by Professor Spiller.

4. The **stratum lemnisci,** which likewise includes masses of gray matter interspersed between the strands of nerve-fibres. The latter are chiefly from that part of the median fillet which terminates within the superior colliculus; a certain number of the fibres, however, are probably derived from the lateral fillet, which, while having its principal quadrigeminal relation with the inferior colliculus, also sends a small contingent to the upper body. The deeper part of the fillet-layer contains a considerable amount of gray matter, in which numerous nerve-cells, usually of small size, are irregularly distributed.

In addition to receiving optic and fillet-fibres, the gray matter of the colliculus gives origin to an important system of descending fibres which establishes connections between the mid-brain and the lower levels of the brain-stem and the spinal cord. These fibres emerge from the ventral border of the colliculus as radially disposed strands which, on nearing the gray matter surrounding the aqueduct, turn ventrally. The more laterally situated fibres, reinforced by those from the opposite side, descend within the tegmental field to end partly in relation with the nuclei within the brain-stem (**tractus tecto-bulbaris lateralis**) and partly within the spinal cord (**tractus tecto-spinalis lateralis**). The medially situated fibres sweep around the Sylvian gray matter and, for the most part, cross the raphe immediately ventral to the posterior longitudinal fasciculus, thus establishing the **fountain decussation** of Meynert (Fig. 960). The further course

of these fibres is downward through the brain-stem and into the anterior column of the cord (**tractus tecto-spinalis medialis**). Whether these fibres are interrupted in small secondary nuclei within the tegmentum, or pass unbrokenly from the collicular cells to the cord is undetermined. It is probable that, as constituents of a **spino-tectal** path, fibres also ascend from the spinal cord to the quadrigeminal bodies. According to Kölliker, some of the radial fibres are traceable through the tegmentum, passing to the outer side of the red nucleus and piercing the tract of the median fillet, and into the substantia nigra, whose cells they probably join as axones. The **commissure** of the superior colliculi is formed by fibres that cross the mid-line to the opposite quadrigeminal body and probably includes, in addition to the axones of cells within the colliculi themselves, fibres from the fillet and optic tracts.

The most important **connections of the superior colliculus**, as may be anticipated from the foregoing description of its structure, are :

1. With the optic tract, without interruption in the lateral geniculate body, by way of the superior brachium. Such fibres serve a special purpose, namely, to carry stimuli which excite pupillary reflexes, by transference to the oculomotor nucleus. 2. With the posterior sensory columns of the spinal cord, indirectly by way of the median fillet. 3. With the cochlear nuclei by way of the lateral fillet, thus establishing a path for audito-visual reflexes. 4. With nuclei of the third, fourth and sixth cranial nerves, controlling the eye-muscles, especially the oculomotor, by way of the posterior longitudinal fasciculus. 5. With the lower levels of the brain-stem and the spinal cord by way of the tecto-bulbar and tecto-spinal tracts.

The **lateral geniculate body** belongs to the diencephalon and may be regarded as a specialized part of the optic thalamus ; the consideration of its structure therefore, properly falls with that of the metathalamus (page 1126).

The Tegmentum.—The tegmental region of the mid-brain includes, as seen in transverse sections (Fig. 961), the U-shaped area extending from the quadrigeminal bodies behind to the crescents of the substantia nigra in front. In the vicinity of the central gray matter that surrounds the Sylvian aqueduct, the tegmentum consists chiefly of a foundation resembling the formatio reticularis seen at lower levels. This substance is produced by the intermingling of transverse or arcuate and longitudinal fibres and a meagre amount of gray matter with irregularly distributed nerve-cells, that fills the interstices between the strands of nerve-fibres. The more lateral and ventral parts of the tegmentum are to a large extent occupied by the prominent fibre-tracts belonging to the fillets and to the superior cerebellar peduncles, or by collections of gray matter, as the red nuclei. Special groups of nerve-cells and of nerve-fibres mark the origin and course of the oculomotor and trochlear nerves.

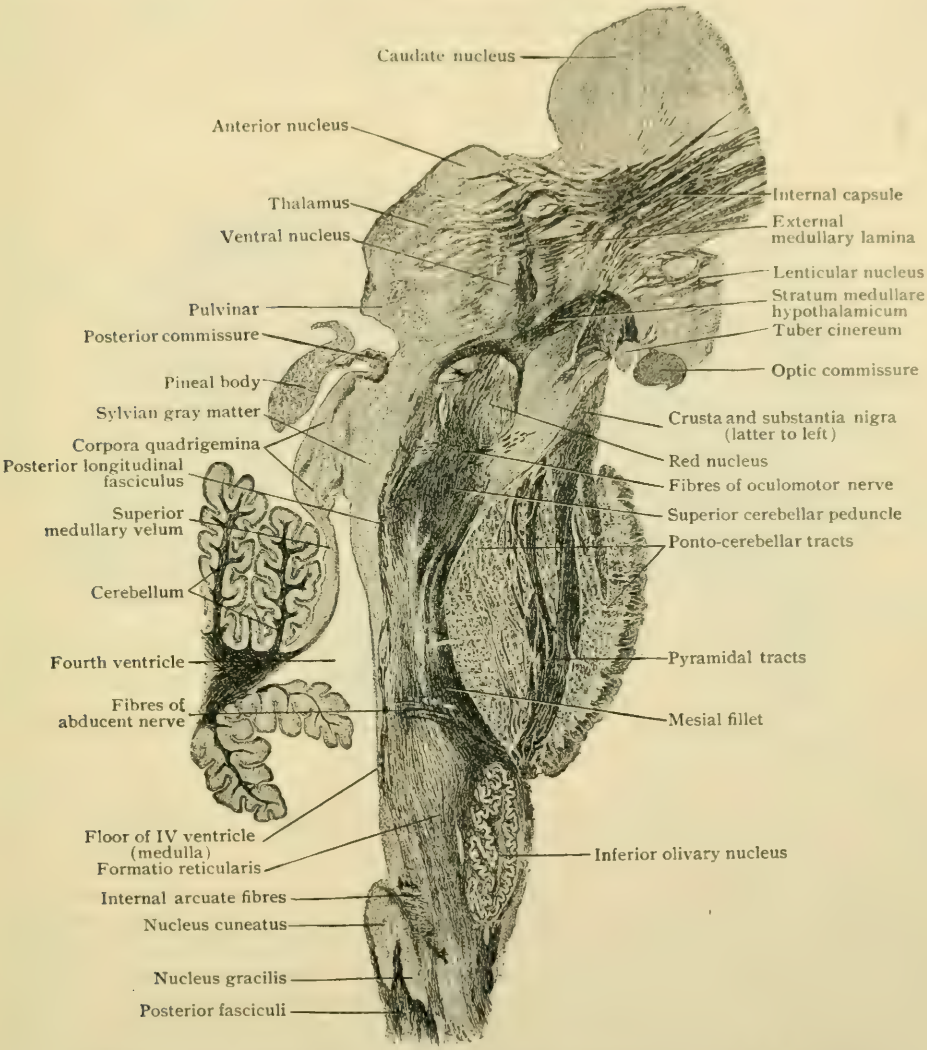
The details of the tegmentum vary with the level of the plane of section. Thus, at the lower end of the mid-brain the tracts of the cerebellar peduncles approach the mid-line as they ascend and those of the fillets assume a more lateral position ; whilst at higher levels these tracts, which lower in the mid-brain are so conspicuous, either terminate to a large extent, or become so broken up as to no longer form impressive bundles.

In sections passing through the lower pole of the inferior quadrigeminal bodies (Fig. 960), the zone overlying the substantia nigra is occupied to a great extent by the median fillet, which here appears as a broad but thin crescentic or comma-shaped field, whose outer and thicker end lies at the periphery and abuts against the base of the dorsally arching tract of the lateral fillet. At the inner end of the median fillet, near the mid-line, an isolated group of obliquely cut fibres sometimes indicates the position of the lemnisco-crustal bundle that appears ventrally among the robust strands of the crusta. Taken together, the two fillets form a compact tract, the outer contour of which, at the level now considered, resembles a horizontally placed Gothic arch, the summit of the curve lying at the surface and the lower and upper limits of the arch being the median and lateral fillets respectively. The lateral fillet continues the sweep of the fillet-stratum along the periphery of the tegmentum until it embraces the lower pole of the inferior colliculus in the manner previously described (page 1110).

Dorsal to the tract of the median fillet, and separated from the latter by a thin layer of compact foundation-substance, the **ventral tegmental field**, lies the broad curved band formed by the blending of the two superior cerebellar peduncles. At lower levels (Fig. 936) these stalks are separate and appear as laterally placed and conspicuous crescentic areas of transversely cut fibres ; but opposite the lower limit of the inferior quadrigeminal bodies the ventral ends of these crescents meet at the mid-line and interlace to form the **decussation of the cerebellar peduncles**. At a slightly higher level, after their decussation has been almost completed (Fig. 961), the cerebellar peduncles appear as prominent rectangular fields, with rounded corners, on each side of and close to the mid-line. These fields of transversely cut fibres represent the peduncles

as they pass upward to the red nuclei, in which a large number of their component fibres end. On each side of the median raphe of the tegmental field and above (behind) the peduncular tract, is seen the posterior longitudinal fasciculus, which here, broader than in the pons, passes close to the ventral side of the nucleus of the trochlear nerve. The attenuated crescentic tract of transversely cut fibres which lies along the lateral margin of the central gray substance, medial to the nucleus of the inferior colliculus, represents the mesencephalic root of the trigeminal nerve. In sections taken slightly below the level of the trochlear nucleus, irregular bundles of obliquely cut fibres mark the dorsally directed course of the fourth-nerve to gain its decussation in the roof of the aqueduct at the lowest limit of the mesencephalon (Fig. 959).

FIG. 962.

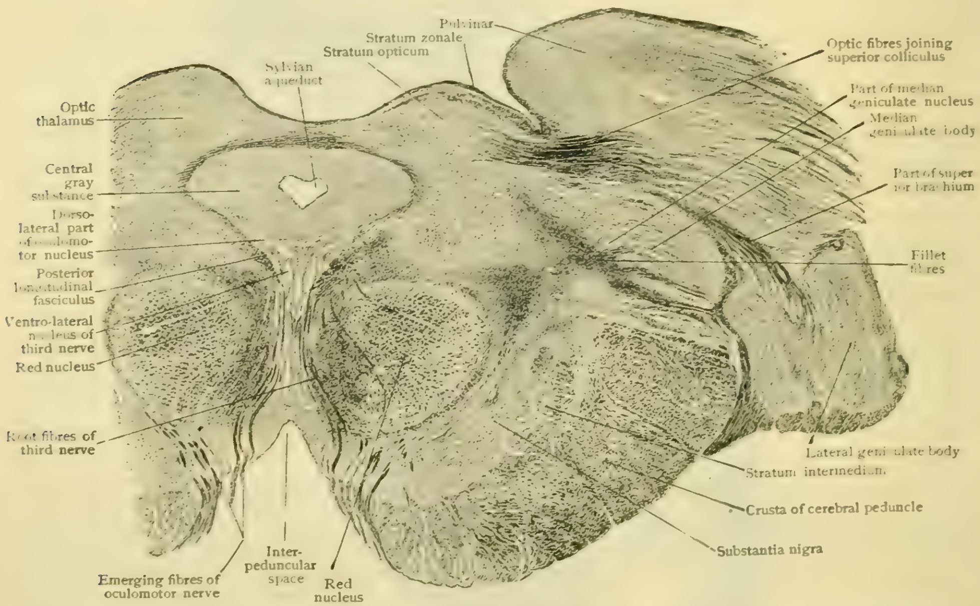


Sagittal section of brain-stem ; plane of section is somewhat lateral to mid-line. × $\frac{3}{2}$. Preparation by Professor Spiller.

As seen in cross-sections passing through the superior quadrigeminal bodies, the details of the tegmentum differ considerably from those at the levels previously stated. The lateral fillet is no longer present as a distinct field, since with the exception of a few strands that are continued into the superior colliculus, its fibres end within the lower colliculus or pass into the inferior brachium. The median fillet now shows (Fig. 963) as a somewhat attenuated crescentic field, lying to the inner side of the obliquely cut inferior brachium, in consequence of many of its fibres having ended within the lower part of the superior colliculus, the more dorsally situated of those remaining being seen within the upper colliculus as the stratum lemnisci.

The most conspicuous object within the tegmentum in the superior half of the mid-brain is a large round reticulated field on each side of the median raphe, which marks the position of the **red nucleus** (**nucleus ruber**). This body, also called the *nucleus tegmenti*, is of an irregular ovoid form (Fig. 963) and of a reddish tint when seen in sections of the fresh brain. Its lower limit corresponds with the level of the lower margin of the superior colliculus, whilst its upper pole extends into the subthalamic region. Its diameter increases towards the upper end and its long axis converges as it ascends, so that the upper enlarged portions of the two nuclei lie close to the mid-line and nearer each other than do the lower poles. Each nucleus consists of a complex of gray matter and nerve-fibres. The latter preponderate below, where the red nucleus receives the fibres of the superior cerebellar peduncle, and are much less numerous above, since many fibres come to an end around the rubral cells. These elements are very variable in shape and size (.020.–060 mm.), but are most often irregularly triangular or stellate. The red nuclei constitute not

FIG. 963.



Transverse section of mid-brain at level O (Fig. 919), passing through superior colliculus and geniculate bodies; red nucleus, and nuclei and root-fibres of oculomotor nerve. Weigert-Pal staining. × 3. Preparation by Professor Spiller.

only important stations in the path connecting the cerebellum and spinal cord, but also probably contribute links in chains uniting the cerebral cortex and the internal nuclei with the cord. Whilst some of the constituents of the superior cerebellar peduncle pass around the red nucleus and continue as *cerebello-thalamic fibres* uninterruptedly to the optic thalamus, the majority of the fibres of this arm end around the cells of the nucleus. Of these many give off axones that proceed brainward as **rubro-thalamic fibres**; others emerge from the ventro-medial surface of the nucleus, cross the mid-line (decussation of Forel) and bend downward as the **rubro-spinal tract.** The latter descends within the tegmentum of the mid-brain and pons, traverses the medulla and finally enters the lateral column of the cord as one of the important but uncertainly defined descending tracts. Other fibres enter the red nucleus on its lateral aspect and establish connections between the cerebral cortex (Dejerine), and probably also the corpus striatum (Edinger), and the nucleus. From the cells of the latter the path is continued by fibres which join the rubro-spinal tract, and in this manner establish an indirect motor path that supplements the cortico-spinal tracts identified with the pyramidal.

The Crusta.—The crusta, or *pes pedunculi*, appears in transverse sections (Fig. 963) as a bold sickle-shaped field that occupies the most ventral portion of the mid-brain. It consists chiefly of longitudinally coursing fibres which, having traversed the internal capsule, are passing from various parts of the cerebral cortex to lower levels in the brain-stem and the spinal cord. The longitudinal fibres are separated into bundles by the invasion of numerous strands from the fibre complex, known as the **stratum intermedium,** which lies along the ventral border of the substantia nigra. The fibres of the crusta comprise three general sets: the *cortico-pontile*, the *cortico-bulbar*, and the *cortico-spinal*.

The **cortica-pontile fibres** include those passing from the cells of the cerebral cortex to the cells of the pontile nucleus as links in the cortico-cerebellar paths. They are represented by the *fronto-pontile* and the *temporo-occipito-pontile tracts*, which occupy approximately the median and lateral fifths of the crusta respectively. The **cortico-bulbar-fibres** include the efferent strands which pass from the motor areas of the frontal lobe to the nuclei of the motor fibres originating in the bulbar portion of the brain-stem (trigeminal, abducent, facial, glosso-pharyngeal, vagus and hypoglossal nerves). These tracts occupy something less than the fifth of the crusta lying next the fronto-pontine tract. The **cortico-spinal fibres** include the great motor strands which, as the pyramidal tracts, are so conspicuous at lower levels. These tracts share with the fronto-bulbar paths the middle three-fifths of the crusta, appropriating approximately the lateral three-quarters of this area (Fig. 1012).

The Median Fillet.—Repeated reference has been made to the median fillet (**lemniscus medialis**) in the preceding descriptions of the brain-stem ; a general consideration of this important sensory tract may here be given. It begins at the lower part of the medulla, about on a level corresponding with the upper limit of the pyramidal decussation, as axones of the cells within the nucleus gracilis. These sweep ventro-medially as the deep arcuate fibres, for the most part cross the raphe, and bend sharply brainward. Succeeding the condensation of the fillet-fibres into the sensory decussation (Fig. 922) which marks the lowest limit of the tract, the fillet receives continuous additions of arcuate fibres from the gracile and cuneate nuclei so long as these collections are present. On reaching the inferior olivary nuclei in its journey brainward, the fillet forms a laterally compressed tract, the *interolivary stratum*, lying immediately dorsal to the pyramids (Fig. 928). Towards the upper end of the pons, the fillet gradually exchanges its sagittal plane and median position for an obliquely horizontal disposition, with an increasing tendency to migrate laterally. The fibres arising from the nucleus cuneatus, which below occupied the ventral part of the fillet, now constitute the lateral part of the tract, whilst those from the nucleus gracilis form its medial portion. Within the mid-brain the median and the lateral fillets form a continuous crescentic tract which, within the upper part of the tegmentum and after the disappearance of the acoustic paths, is represented chiefly by the superficial and laterally placed tract which the median fillet has now become. A considerable part of its fibres end around the cells of the deeper gray stratum of the superior colliculus, some passing over the aqueduct to the colliculus of the opposite side. The remaining fibres continue upward through the tegmentum, lateral and dorsal to the red nucleus, and the subthalamic region, to terminate chiefly in relation with the cells within the ventral part of the optic thalamus. After such interruption the impulses are carried by fibres arising within the thalamus to various parts of the cerebral cortex. Whether fillet-fibres gain the cortical gray matter without interruption within the thalamus is uncertain. Other fibres, said to be derived from the cuneate nucleus, end in the corpus subthalamicum, and the lenticular nucleus (globus pallidus), from whose cells a certain number of fibres proceed by way of a strand placed above the optic chiasm, the *commissure of Meynert*, to the globus pallidus of the opposite side. Still other fibres are traceable into the posterior commissure of the brain and into the mammillary body.

The constituents of the median fillet, however, are by no means restricted to the fibres arising from the gracile and cuneate nuclei of the posterior columns, but include numerous important accessions from the reception-nuclei of all the sensory cranial nerves connected with the brain-stem. From the cells within the more

extensive of such nuclei, as those within the column of substantia gelatinosa accompanying the spinal root of the trigeminus, numerous arcuate fibres sweep towards the raphe and, with few exceptions, cross to join the median fillet of the opposite side. In this manner provision is made for the transmission to the higher receptive centres of sensory impulses collected not only by the strands of the posterior column of the cord, but also by the sensory fibres of the cranial nerves attached to the brain-stem.

Although the principal components of the fillet-tract are the **bulbo-tecto-thalamic strands,** some fibres running in the opposite direction are also present. Some of these probably arise from cells within the optic thalamus and the corpora quadrigemina. Others are efferent strands which establish connections between the cortical gray matter and the nuclei of the motor cranial nerves, especially the facial and hypoglossal. These **cortico-bulbar tracts** descend within the crusta to the lower end of the cerebral peduncle; then, leaving the latter, they traverse the stratum intermedium and in the upper part of the pons join the median fillet and descend within its ventro-median part as far as the superior end of the hypoglossal nucleus. During their course, the fibres of this **crustal fillet,** as it is called, for the most part undergo decussation on reaching the levels of the motor nucleus for which they are destined; some fibres, however, possibly end around the cells of the nucleus of the same side.

Fig. 964.

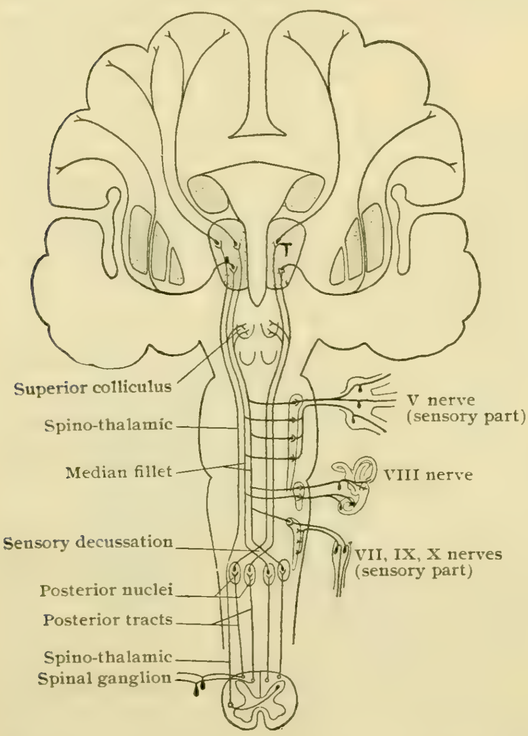


Diagram showing chief afferent constituents of median fillet.

The Posterior Longitudinal Fasciculus.—This bundle (**fasciculus longitudinalis medialis**) is an association path of fundamental importance, being present in all vertebrates. As a distinct strand it begins in the superior part of the mid-brain and thence is traceable as a continuous tract through the tegmental region of the pons, the dorsal and lateral ventral field of the medulla into the anterior ground-bundle of the spinal cord. Throughout the greater part of its course through the brain-stem, its position is constant, the fasciculi of the two sides lying close to the median raphe and immediately beneath the gray matter flooring the Sylvian aqueduct and the fourth ventricle (Figs. 959, 961). In the lower part of the medulla, the bundle gradually leaves the ventricular floor and rests upon the dorsal border of the median fillet, and, at the level of the pyramidal decussation, where the fillet no longer intervenes, lies behind the pyramid and at some distance from the mid-line. Lower, it assumes a more ventral position, to the medial side of the isolated anterior cornu, and, finally, enters the anterior column of the cord to be lost within the upper part of the ground bundle.

The fasciculus includes association fibres of varying lengths, some of which are ascending and others descending paths. The constitution of the bundle is, therefore, continually changing, the loss of certain fibres being replaced by the addition of others. Its fibres are among the very first in the brain to become medullated, and begin to acquire this coat during the fourth fœtal month (Hösel).

Notwithstanding the admitted importance of the tract and the prolonged study that it has received, much remains to be determined concerning the source and connections of the many constituents which undoubtedly go to form the bundle. Among the more certain of these components the following may be mentioned:

1. At the upper end of the fasciculus a considerable number of fibres arise from the cells of the **nucleus of the posterior commissure**, or *Darkschewitsch's nucleus*, which lies in advance of the oculomotor nucleus, within the gray matter surrounding the superior end of the Sylvian aqueduct. According to Edinger an additional contingent takes origin from a nucleus (**n. fasciculi longitudinalis medialis**) within the gray matter of the floor of the third ventricle in the vicinity of the corpus mammillare. The contributions from both these sources join the fasciculus as crossed fibres from the nuclei of the opposite side.

2. The fibres arising from the vestibular (Deiters') nucleus constitute an important element of the posterior longitudinal bundle, since they establish reflex paths for equilibration impulses. These fibres, both crossed and uncrossed, join the fasciculus and pass in both directions. Those passing brainward have as their chief objective point the oculomotor nucleus, although the nuclei of the sixth and fourth nerves receive fibres or collaterals. In this manner the filaments supplying the various ocular muscles are brought under the influence of the vestibular impulses. It is probable that the facial nucleus likewise receives collaterals, if not main stems, of the vestibulo-nuclear fibres.

Fig. 965.

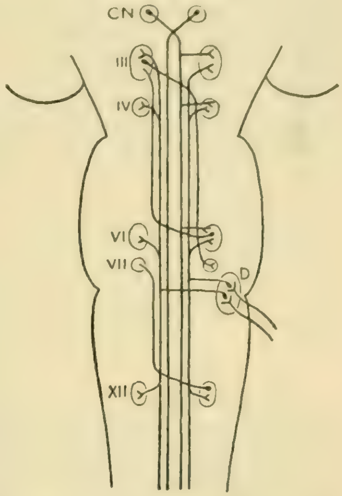


Diagram showing chief constituents of posterior longitudinal fasciculus. III, IV, VI, VII, XII, nuclei of respective nerves; D, vestibular (Deiters') nucleus; CN, common nucleus of posterior commissure and posterior longitudinal fasciculus.

3. Upon clinical and experimental evidence, it may be assumed that fibres pass by way of the longitudinal bundle from the abducent nucleus to that part of the oculomotor nucleus sending fibres to the internal rectus muscle of the opposite side (perhaps also from the nucleus of the third nerve to that of the abducens of the same side), by which arrangement the harmonious action of the internal and external recti muscles is insured. Basing their conclusions upon similar evidence, many anatomists accept the existence of fibres which pass by way of the posterior longitudinal bundle from the oculomotor nucleus to the cells of the facial nucleus (page 1251) from which proceed the fibres supplying the orbicularis palpebrarum and the corrugator supercilii. In this manner the coördinated action of these muscles and the levator palpebræ superioris is explained. A similar connection is probably established by the posterior longitudinal bundle between the nucleus of the hypoglossal and that of the facial nerve, whereby the closely associated movements of the lips and tongue are assured. That the function of the posterior fasciculus is by no means limited to association of the nuclei of the ocular nerves is evident from the fact that in animals or individuals in which such centres are wanting (due to absence or imperfect development of the visual organs) the bundle is nevertheless well represented.

4. Fibres arise from the reception-nuclei of the remaining sensory nerves of the brain-stem and pass to the posterior longitudinal fasciculus of the same and the opposite side. On entering the bundle, they course in both directions and by means of their collaterals and stem-fibres send end-brushes to the nuclei of the motor nerves, in this manner establishing direct reflex areas between the afferent and efferent paths.

Strictly considered, it is probable that the fibres establishing connections with the nuclei of the sensory nerves constitute a small separate tract, lying within the central gray matter dorso-lateral to the posterior longitudinal bundle. This path has been called the *fasciculus longitudinalis dorsalis* of Schütz, while the main bundle is then termed the *fasciculus longitudinalis medialis.* In order to avoid confusion, both sets of fibres are here regarded as parts of one path, the posterior longitudinal bundle.

DEVELOPMENT OF THE MESENCEPHALON.

Of the three primary cerebral vesicles, the mid-brain undergoes least change. Although much smaller than either of the other segments of the brain-tube, its prominent position, lying as it does at the summit of the cephalic flexure, makes it conspicuous in the early developing brain. During the enormous expansion upward and backward incident to the development of the cerebral hemispheres in man, the mid-brain becomes covered in and deposed to a dependent position and a relatively small size. For a time possessing a spacious cavity, it fails to keep pace with the growth of the adjoining parts; its walls thicken and its lumen becomes eventually reduced to the narrow Sylvian aqueduct.

The dorsal zones of the lateral wall of the mid-brain give rise to the quadrigeminal plate, whose external surface is at first smooth but later marked by a temporary median longitudinal ridge. About the third fœtal month, with the exception of its lower end, which persists as the frenulum veli, this ridge is succeeded by a longitudinal groove bounded on either side by an elevation. The elevations of the two sides mark the appearance of the corpora bigemina, corresponding to the optic lobes of the lower vertebrates. During the fifth month, an obliquely transverse furrow forms on each side, by which the paired elevations are subdivided into four eminences, the corpora quadrigemina. About this time the corpora geniculata, which however belong developmentally to the diencephalon, are also differentiated and for awhile are relatively very large and prominent.

The ventral zones greatly thicken and give origin to the tegmentum, including the nuclei of the oculomotor and of the trochlear nerves and, perhaps, the red nuclei, and the mantle layer of the cerebral peduncles with the interpeduncular substance. The floor-plate becomes compressed between the expanding ventral zones of the lateral walls and probably is represented by the raphe. Since the fibre-systems of the crustæ are, for the most part, derived from sources outside the brain-stem, their appearance within the peduncles follows a secondary ingrowth, and only after such invasion do the cerebral crura present their characteristic ventral prominence. The cortico-pontile tracts share with the pyramidial fibres the characteristic of tardy myelination, since they do not acquire their medullary coat until some time after birth. Among the earliest of the cortico-bulbar fibres to become medullated (a few weeks after birth) are those destined for the motor cranial nerves by way of the crustal or pyramidal fillet of Flechsig. According to Kölliker, the stratum intermedium, which is closely related to the substantia nigra, not only in position but also by the destination of many of its fibres, contains a considerable number of medullated fibres by the ninth fœtal month.

THE FORE-BRAIN.

It will be recalled that the fore-brain, the anterior primary cerebral vesicle, gives rise to two subdivisions, the *telencephalon* and the *diencephalon* (page 1060). Since the latter lies immediately in front of the mid-brain, in following the order in which the brain-segments have been described, the diencephalon next claims attention.

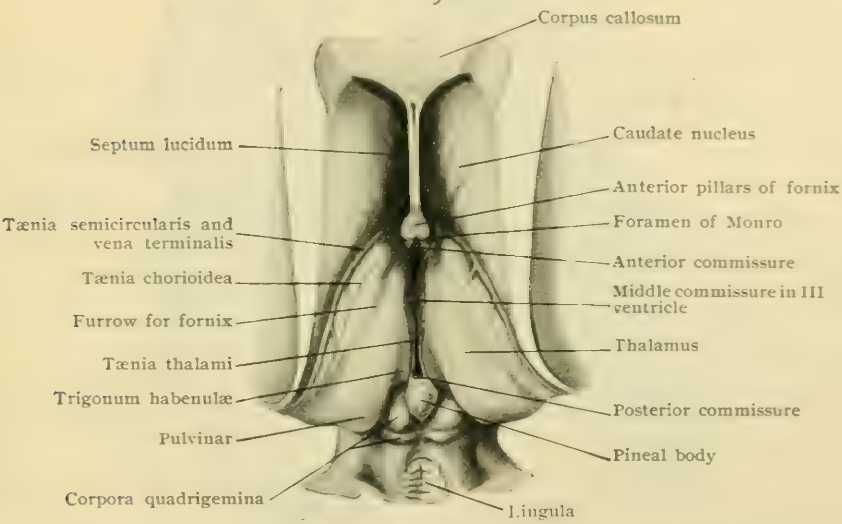
THE DIENCEPHALON.

Strictly considered upon the basis of the classic subdivision suggested by His, the diencephalon, or *inter-brain*, includes (1) a large dorsal portion, the **thalamencephalon** and (2) a small ventral portion, the **pars mammillaris hypothalami,** together with (3) the enclosed remains of the posterior part of the cavity of the fore-brain, as represented by the greater part of the *third ventricle*. The thalamencephalon, in turn, includes: (*a*) the **thalamus,** (*b*) the **epithalamus**, comprising the pineal body, the habenular region and the posterior commissure, and (*c*) the **metathalamus,** including the corpora geniculata. Since, however, the description of the third ventricle and its surrounding structures—the essential features of this segment of the adult brain—requires the inclusion of parts belonging to the telencephalon (pars optica hypothalami), it will be more convenient to disregard their strict developmental relations and include the representatives of the pars optica in the consideration of the diencephalon.

The Thalamus.—After removal of the overlying structures—the corpus callosum, the fornix and the velum interpositum—the thalami (**thalami**), also called the *optic thalami*, are seen as two conspicuous masses of gray matter separated by a narrow cleft, the third ventricle. Each thalamus is an ovoid ganglionic mass, blunt wedge-shaped, as seen in cross-sections (Fig. 967), whose long axis extends from the narrow anterior pole backward and outward. Of its four surfaces, the lateral and ventral are blended with the surrounding nervous tissue, and the mesial and dorsal are to a large extent free. The large **superior surface** is irregularly triangular in outline, slightly convex in the frontal plane and markedly so in the sagittal, and covered with a thin layer of nerve-fibres, the **stratum zonale,** which imparts a whitish color. This stratum is composed of fibres which are traceable on the one hand to the optic tract, and on the other to the optic radiation in the hind part of the internal capsule. Laterally, the superior surface is separated from the caudate nucleus by a groove which obliquely crosses the floor of the lateral ventricle and lodges a narrow band of fibres, the **tænia semicircularis** (stria terminalis) and, in its anterior part, the vein of the corpus striatum. In its front half, where it bounds the

ventricle, the inner border is sharply defined from the mesial surface by a delicate but well defined ridge, **tænia thalami,** produced by the thickening of the ependyma of the third ventricle, along its line of reflection onto the membranous roof, and the underlying strand of nerve-fibres, the **stria medullaris.** Traced backward, the tænia thalami becomes continuous with the stalk of the pineal body. Between this ridge and the diverging mesial border of the upper surface of the thalamus, is included a narrow depressed triangular area, known as the **trigonum habenulæ.** It lies on a distinctly lower level than the adjoining convex upper surface of the thalamus. Since it contains a special nucleus and belongs to the epithalamus, its description will be deferred until that region is considered (page 1123). The upper surface is not quite even, but subdivided by a shallow oblique furrow, which runs from before backward and outward and marks the position of the overlying lateral border of the fornix. External to this furrow lies a free marginal zone that forms a part of the floor of the lateral ventricle ; internal to it is an attached inner zone over which the velum interpositum is united to the thalamus. By the attachment of this

FIG. 966.

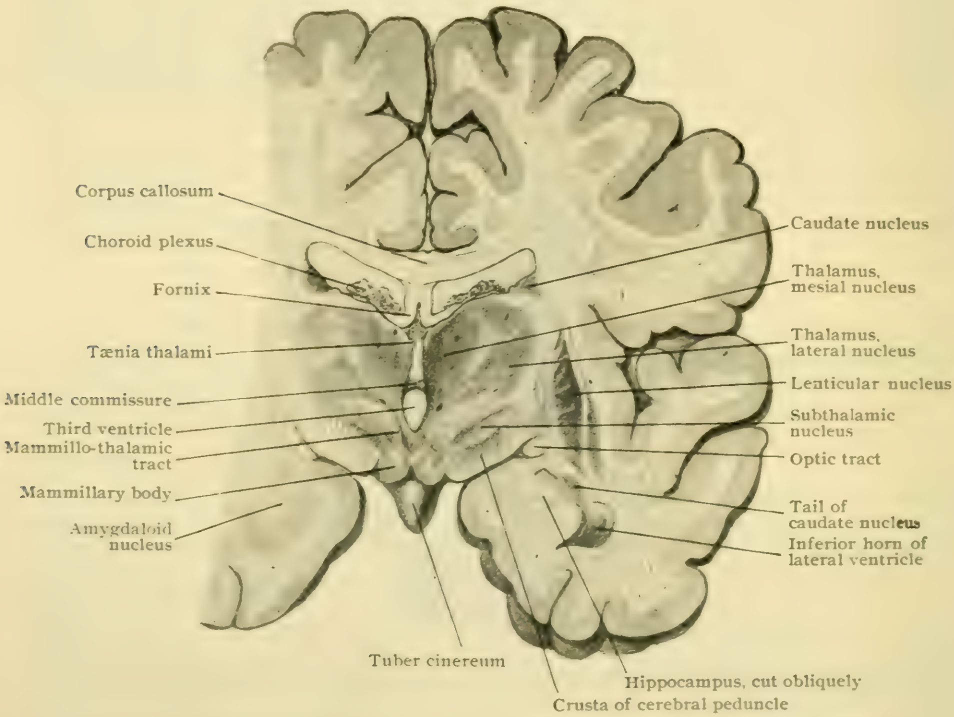


Thalami, caudate nuclei and ventricles viewed from above after removal of corpus callosum, fornix and velum interpositum ; third ventricle shows as narrow cleft between mesial surfaces of thalami.

sheet to the fornix above and to the thalamus below, direct communication between the third and lateral ventricles is shut off save through the foramen of Monro. In front, the superior surface ends on the rounded elevation (**tuberculum anterius thalami**) which marks the anterior pole of the ganglion, while behind it goes over onto the prominent posterior projection, the **pulvinar,** which overhangs the superior brachium and the corpora geniculata. The **mesial surface** forms the greater part of the lateral wall of the third ventricle. It is covered by a layer of gray matter prolonged from the central gray of the Sylvian aqueduct, over which stretches the immediate lining of the ventricle, the ependyma. The upper boundary of the mesial surface is sharply defined by the tænia thalami, which behind is continuous with the stalk of the pineal body (Fig. 966). Its lower limit is indicated by an oblique furrow, the **sulcus hypothalamicus,** which separates the thalamic from the hypothalamic regions. Somewhat in advance of their middle, the mesial surfaces of the two thalami are connected by a bridge of gray matter, known as the **middle commissure** (**massa intermedia**), usually about 7–8 mm. in diameter and oval in section, but very variable in thickness and form. From the meagre number of medullated nerve-fibres that it contains, its importance, at least in man, seems to be small. The **lateral surface** of the thalamus is inseparably blended with the adjacent thick and conspicuous stratum of white matter, the **internal capsule.** which intervenes between the thalamus and the more laterally placed lenticular

nucleus, and establishes the important pathway transmitting the fibre-tracts connecting the cerebral cortex with the thalamus and with the lower levels by way of the crusta of the cerebral peduncle. Since the innumerable fibres which pass to and from the thalamus along its ventro-lateral surface interlace, this surface is covered by a distinct reticulated stratum, to which the name **external medullary lamina** is applied. The **ventral surface** is also attached, but instead of being united with the internal capsule, as is the lateral, it rests upon and is intimately blended with the upward prolongation of the tegmental portion of the cerebral peduncle, here known as the **subthalamic tegmental region**, presently to be described (page 1127).

FIG. 967.



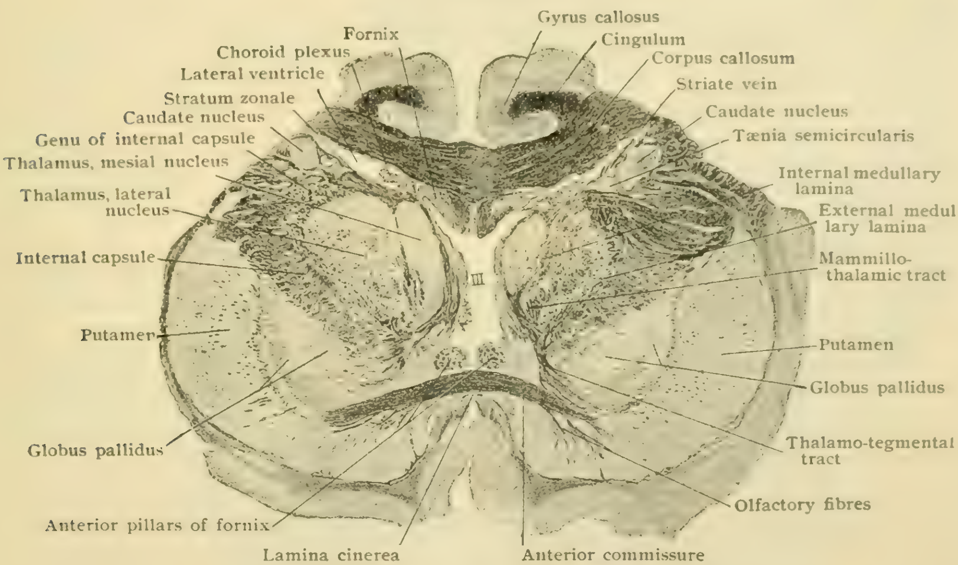
Frontal section of brain passing through thalami, middle commissure and mammillary bodies.

Structure of the Thalamus.—Although composed chiefly of gray matter, the thalamus is partially surrounded and penetrated by tracts of white matter. In addition to being invested on its superior and ventro-lateral surfaces by the stratum zonale and the external medullary lamina respectively, the general ganglionic mass is subdivided by a vertical internal sheet of fibres, continuous with the stratum zonale and known as the **internal medullary lamina**, into three fairly marked nuclei, the anterior, the mesial and the lateral (Fig. 967). Of these the **lateral nucleus** is much the largest and is included between the external and internal medullary laminæ. Whilst the lateral nucleus does not reach as far forward as the anterior pole of the thalamus, its caudal extremity includes the entire pulvinar. The lateral nucleus consists histologically of an intricate complex of nerve-fibres and cells. The latter are in general of the multipolar type, although very variable as to details of form and size. Two principal types are recognized by Kölliker, the one being elongated or fusiform and possessed of relatively few branches, and the other being stellate and provided with richly branched dendrites. Many of the fibres represent paths ending within the thalamus and therefore terminate in arborizations around the thalamic cells; others are the axones of such cells and pass to various parts of the cortex or other parts of the brain. The histological characteristics of the lateral nucleus, in the

main hold good for the other nuclei, although the lateral nucleus is particularly rich in fibres, and therefore of a paler tint, on account of its close relations to the internal capsule and the tegmentum of the cerebral peduncle.

The **mesial nucleus** lies between the central gray matter of the ventricular wall and the internal medullary lamina, and is separated by the latter from the lateral nucleus. Its caudal end is bordered internally by the ganglion habenulæ, and, behind, by the pulvinar. The **anterior nucleus**, the smallest of the three, is a wedge-shaped mass, whose rounded base looks forward and corresponds to the anterior tubercle, and whose apex is directed backward and lies between the front ends of the mesial and lateral nuclei, separated from these by the internal medullary lamina, which divides into two diverging levels that embrace the anterior nucleus. In addition to its contribution of radiating fibres which take part in the production of the thalamic radiation, the anterior nucleus contains a compact bundle of fibres traceable into the mammillary body on the base of the brain. These are the constituents of the **mammillo-thalamic tract**, or *bundle of Vicq d'Azyr*, by which a large part of the fibres

FIG. 968.



Oblique frontal section through thalamus and anterior commissure; Weigert-Pal staining. × $\frac{3}{2}$.
Preparation by Professor Spiller.

coursing within the anterior pillar of the fornix are carried to the thalamus (page 1159). The entire ventral part of the thalamus is occupied by an illy-defined mass of gray matter, known as the **ventral nucleus**, which lacks sharp definition from the overlying nuclei and in fact is continuous with the lateral nucleus. The ventral nucleus presents a differentiation into the **nucleus centralis** of Luys, which occupies a mesial position and appears round in section (Fig. 970), and receives fibres from the red nucleus and the posterior commissure, and the **nucleus arciformis**, which lies ventro-lateral to the preceding nucleus and is crescentic in outline. The ventral nucleus is of importance, not only because it receives the great sensory paths, but also on account of its phylogenetic rank, since, according to Edinger, it, together with the ganglion habenulæ, represents the oldest of the thalamic nuclei and is found throughout the vertebrate series.

Connections of the Thalamus.—Broadly considered, the thalamus may be regarded as a great ganglionic internode interposed in the corticipetal paths around whose cells most of the constituents of the important secondary paths conveying afferent impulses from the spinal cord, the brain-stem and the cerebellum end,

and from whose cells corticipetal fibres pass to all parts of the cerebral cortex and to the corpus striatum. Further, it must be understood that the thalamus receives fibres from all parts of the cerebral cortex, and, lastly, that from it proceed efferent fibres to the lower centres within the brain-stem and the cord. It is evident, therefore, that the connections of the thalamus are very intricate and far reaching.

1. The **lower thalamocipetal tracts** include: (*a*) those passing directly from the spinal cord, as the *spino-thalamic* and possibly a part of Gowers' tract; (*b*) those passing from the various nuclei by way of the *median fillet;* (*c*) those passing from the cerebellum, either directly, as the *cerebello-thalamic* tract, or, after interruption in the red nucleus, as the *rubro-thalamic;* (*d*) probably other tracts which arise within the tegmental area of the brain-stem. The fibres from the various sources enter the under surface of the thalamus to end within the ventral nucleus, or by means of the internal medullary lamina to be distributed to the other nuclei.

Fig. 969.

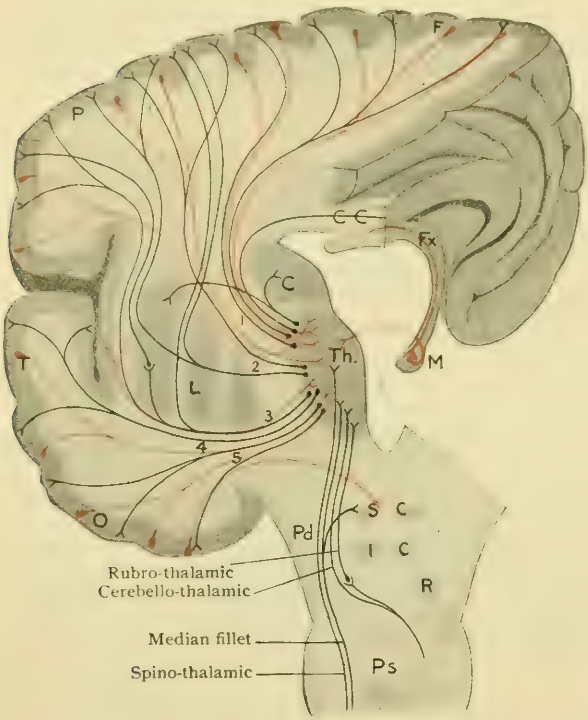


Diagram showing chief connections of thalamus; black fibres represent afferent tracts ending in thalamus and thalamo-cortical paths; red fibres are the cortico-thalamic and strio-thalamic paths; *Th*, thalamus; *C*, *L*, caudate and lenticular nuclei; *C*, *C*, corpus callosum; *F*, *P*, *T*, *O*, frontal, parietal, temporal and occipital lobes; *Fx*, fornix; *M*, mammillary body; *Pd*, cerebral peduncle; *SC*, *IC*, superior and inferior colliculi; *R*, red nucleus; *Ps*, pons; *1*, frontal stalk; *2*, parietal stalk; *3*, *4*, lenticular and temporal parts of ventral stalk; *5*, occipital stalk.

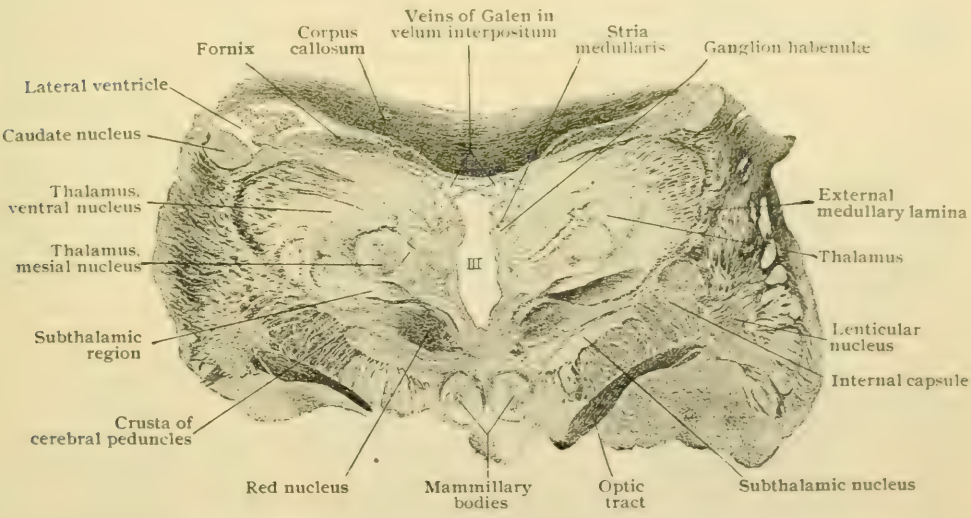
2. The **thalamic radiation** comprises the fibres which stream from the latero-ventral surface of the thalamus to all parts of the hemisphere (*thalamo-cortical*), some crossing by way of the corpus callosum to the opposite side, as well as those which pass in the opposite direction (*cortico-thalamic*) towards the ganglion. Although as they traverse the external medullary lamina the fibres are not particularly grouped, their various relations to the cortex or other parts are established by different and more or less definite paths. These are designated as the *stalks* of the thalamus, of which a frontal, a parietal, an occipital and a ventral are conventionally distinguished. The anterior or **frontal stalk** emerges from the fore-part of the lateral surface of the thalamus, traverses the anterior part of the internal capsule between the caudate and lenticular nuclei, to which it distributes fibres, and finally gains the cortex of the frontal lobe. From the cells of this region, *cortico-thalamic fibres* follow in reversed order the paths just mentioned, thus establishing a double relation between the cortex and the basal ganglion. In addition to the preceding cortico-thalamic fibres, the antero-ventral part of the thalamus receives a strand from the cortex of the olfactory bulb. The **parietal stalk** leaves the lateral surface of the thalamus and enters the internal capsule and often the lenticular nucleus, in its course to the parietal cortex. Other corticipetal fibres, destined for the parietal and adjacent parts of the frontal lobe, are the continuations of the path of the mesial fillet. To a large extent these fibres pass from the ventral thalamic nucleus outward to the under surface of the lenticular nucleus, then bend upward and traverse the lenticular nucleus by way of the medullary striæ or the globus pallidus to gain the cortex. Other fibres continue the fillet-path by entering the internal capsule and thus, perhaps, directly proceed to the cortex. The **occipital stalk** includes the fibres that connect the thalamus with the visual cortical areas of the occipital and parietal lobes. They issue from the lateral surface of the pulvinar, and as the

optic radiations sweep outward and backward around the posterior horn of the lateral ventricle to end in the cortex. The **ventral stalk** is complex in its relations, since its fibres include two systems. Emerging from the fore-part of the ventral surface of the thalamus, from the lateral and mesial nuclei, the stalk passes downward and outward beneath the lenticular nucleus. Its lower part, known as the *ansa peduncularis*, continues laterally into the cortex of the temporal and of the central lobe; its upper part, the *ansa lenticularis*, closely skirts the adjacent border of the lenticular nucleus which it enters to gain the putamen, or, continuing through the lenticular nucleus by way of the medullary laminæ, to reach the caudate nucleus. Under the name *tractus strio-thalamicus*, are included the fibres which pass from the caudate nucleus and the putamen to the thalamus, subthalamic body and red nucleus, a small number of fibres probably entering the thalamus from the caudate nucleus by the more direct route of the internal capsule.

3. The **stratum zonale**, the thin layer of white matter which covers the superior aspect of the thalamus, consists in large part of thalamocipetal fibres derived from the optic tract or the optic radiation. Those from the lateral root of the tract superficially cross the external geniculate body and spread over the thalamus, while those from the occipital cortex by way of the optic radiation invest the pulvinar. Other contributions to the stratum zonale include fibres from the temporal cortex by way of the ventral stalk.

The Epithalamus.—Under this subdivision of the thalamencephalon are included: (1) the *trigonum habenulæ*, (2) the *pineal body*, and (3) the *posterior commissure*—all structures closely associated with the superior and posterior boundaries of the third ventricle.

FIG. 970.



Oblique frontal section through thalamus and subthalamic region; Weigert-Pal staining. × ⅘. Preparation by Professor Spiller.

The **trigonum habenulæ** is the narrow triangular area lying between the sharply defined edge (tænia thalami) of the ventricular wall internally and the diverging mesial border of the upper surface of the thalamus externally (Fig. 966). Its surface is depressed and at a lower level than that of the thalamus and behind is continuous with a mesially curving strand, the **pineal peduncle.** Beneath the ridge of thickened ependyma marking the **tænia thalami,** lies a distinct strand of nerve-fibres, the **stria medullaris,** while at a still deeper level and covered by the superficial fibres is situated an aggregation of small nerve-cells, known as the **ganglion habenulæ.** The source of the fibres composing the stria medullaris and the connections of the ganglion habenulæ are still uncertain. It is probable, however, that many components of the stria are associated with the olfactory centres and include: (1) *olfacto-habenular fibres*, which arise from cells within the septum

lucidum and the olfactory area, and (2) *cortico-habenular fibres*, which spring from the cortical cells within the hippocampus or the adjacent region, and by way of the fornix and its anterior pillar are carried to the fore-end of the thalamus, whence they pass backward within the medullary stria. (3) Other *thalamo-habenular fibres* also probably join the stria medullaris from the interior of the thalamus. Whilst many of the fibres composing the stria end around the cells of the ganglion habenulæ, some continue backward, without interruption, within the strand known as the peduncle of the pineal body, cross to the other side in the bundle bearing the name, **commissura habenulæ,** and end in relation with the cells of the opposite habenular nucleus. The ganglion habenulæ (Fig. 970), in turn, gives origin to an important bundle, the **fasciculus retroflexus** of Meynert, which arches downward and backward, passing at first between the central gray matter of the third ventricle and the thalamus proper, and later to the medial side of the red nucleus, to reach the base of the brain, and for the most part to end around the cells of the **interpeduncular ganglion**. This nucleus, which in many animals is a well-defined collection of cells, in man is represented by a more scattered median cell-group within the posterior perforated substance close to the anterior border of the pons. The fasciculus, also termed the **habenulo-peduncular tract,** receives contributions from the ganglion habenulæ of both sides, some fibres having crossed in the habenular commissure; although the majority of its fibres end, mostly crossed, in the interpeduncular ganglion, not a few may be traced farther caudally within the tegmentum of the brain-stem (Obersteiner), as may also the fibres from the cells of the ganglion interpedunculare.

The Pineal Body.—The pineal body (**corpus pineale**), also often called the *epiphysis*, is a cone-shaped organ, from 8–10 mm. in length, attached to the posterior extremity of the roof of the third ventricle. It is slightly compressed from above downward and rests, with its *apex* pointing backward, on the dorsal aspect of the mid-brain in the triangular pineal depression between the superior corpora quadrigemina (Fig. 966). Its *base*, as its anterior end is called, is attached above to the commissura habenulæ, from which on each side a narrow but distinct ridge, the *pineal stalk*, curves forward to become continuous with the stria medullaris. Below, its base is united with the posterior commissure of the brain overlying the entrance into the Sylvian aqueduct. Between the habenular and posterior commissures a small pointed diverticulum, the *pineal recess*, extends from the third ventricle for a very short distance into the pineal body, and thus recalls the early condition in which the organ is developed as a tubular outgrowth in the roof-plate of the diencephalon. This relation to the thin ventricular roof the body retains, its apex later becoming closely surrounded by and embedded within the loose vascular tissue of the pia mater.

FIG. 971.

Section of pineal body showing calcareous concretions or brain-sand. × 130.

The **structure** of the pineal body, as seen in cross-section (Fig. 971), includes a reticular framework of connective tissue trabeculæ, whose meshes are filled with

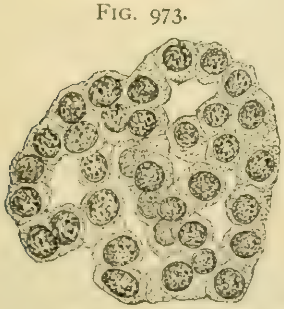
rounded or sometimes elongated epithelial cells, which often contain brownish pigment. With the exception of a few nerve-filaments in the anterior part, probably sympathetic in origin and destined for the blood-vessels, and a dense net work of neuroglia fibres in the under part, the pineal body contains no elements of a nervous character, nerve-cells being absent. Quite commonly the adult organ encloses a variable number of concretions, often called *brain-sand* (*acervulus*), which consist of laminated particles composed of calcium carbonate and phosphate mingled with organic material. They may be of microscopic dimensions, or reach the size of a millet seed, and by aggregation assume a mammillated form.

FIG. 972.

Sagittal section of pineal organ of lizard (*Lacerta agilis*) embryo. × 175.

The significance of the pineal body long remained an unsolved riddle and served as the theme for unrestrained speculation. The embryological and comparative studies of Graaf, Spencer and others have shown that in many of the lower animals, especially in the reptiles (lizards), the pineal body reaches a high degree of development and is a flattened cup-shaped organ connected with the brain by a stalk containing nerve-fibres. The structural resemblances to the invertebrate visual organ suggested a possible similarity of purpose in the higher types, an assumption that was strengthened by the fact that in certain lizards the pineal body not only is borne by a stalk but reaches an interparietal subcutaneous position on the head by passing through or lying within a special foramen in the skull. The organ was, therefore, designated the **pineal eye**, although probably in no existing animal a functionating structure. While such a superficial position in the adult is very exceptional, the embryonic relations in many reptiles (Fig. 972) are very suggestive of the probable significance of the pineal body, at least in such form as a rudimentary sense organ, although not necessarily an eye. These conclusions are likewise suggestive in forming our conceptions concerning the pineal body in man, which is now by many regarded as representing a very imperfectly developed and greatly modified sensory structure.

FIG. 973.



Small portion of pineal body, showing constituent cells more highly magnified. × 600.

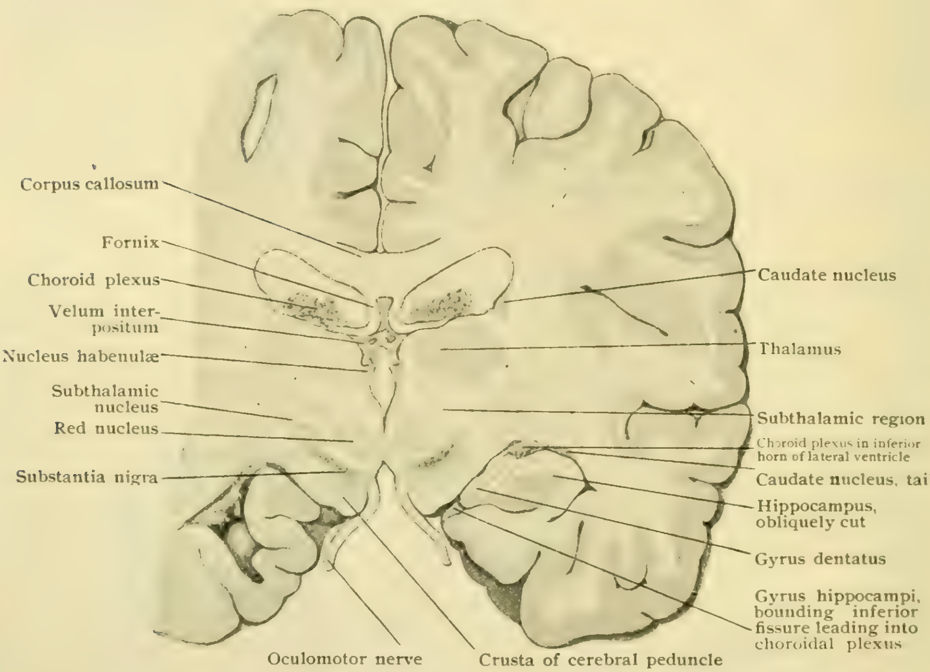
Although strictly belonging to the telencephalon, mention may here be made of a second evagination, know as the **paraphysis**, which arises from the roof-plate of the fore-brain. The pouch appears in advance of the pineal outgrowth and is a temporary structure, seemingly being in nature comparable to an outwardly directed choroid plexus. The paraphysis has been described in the lower vertebrates, including reptiles and birds, in some mammals and, indeed, according to the observations of Francotte and of Ewing Taylor, it is not improbable that a corresponding evagination is recognizable in the early human embryo.

The **posterior commissure** (**commissura posterior cerebri**) is a narrow but distinct cord-like band of white matter which overlies the superior entrance into the Sylvian aqueduct (Fig. 976) and is partially masked by the habenular commissure and pineal peduncle above. Behind and laterally it is continuous with the superior colliculi. The commissure provides the paths by which fibres from various sources undergo median decussation, but the details and connections of its component fibres are only imperfectly understood. Among its probable constituents are: (1) fibres originating in the nucleus of the posterior commissure and also from the nucleus of the posterior longitudinal fasciculus (**nucleus fasciculi longitudinalis posterior**), which occupies the gray matter of the floor of the third ventricle near the mammillary bodies (page 1117); (2) fibres from the posterior part of the thalamus of the

opposite side which descend within the tegmentum, lateral and ventral to the posterior longitudinal fasciculus; (3) fibres which cross to join the fasciculus retroflexus; (4) fibres from the median fillet and (5) from the superior cerebellar peduncle which traverse the commissure to reach the opposite thalamus; (6) perhaps fibres from the deeper gray stratum of the corpora quadrigemina to the cerebral cortex of the other side. Its presence in all vertebrates and the very early acquisition of a medullary coat by its fibres indicate, as pointed out by Edinger, the fundamental character of the commissure.

The Metathalamus.—This subdivision of the thalamencephalon includes embryologically both the median and lateral geniculate bodies. Since in the fully formed

FIG. 974.



Frontal section of brain passing through thalami, subthalamic region and cerebral peduncles; inferior horn of lateral ventricle with hippocampus in section also seen.

brain the former are closely associated with the inferior colliculi and their arms, the inferior brachia, they may be conveniently described in connection with the midbrain, as has been done (page 1110).

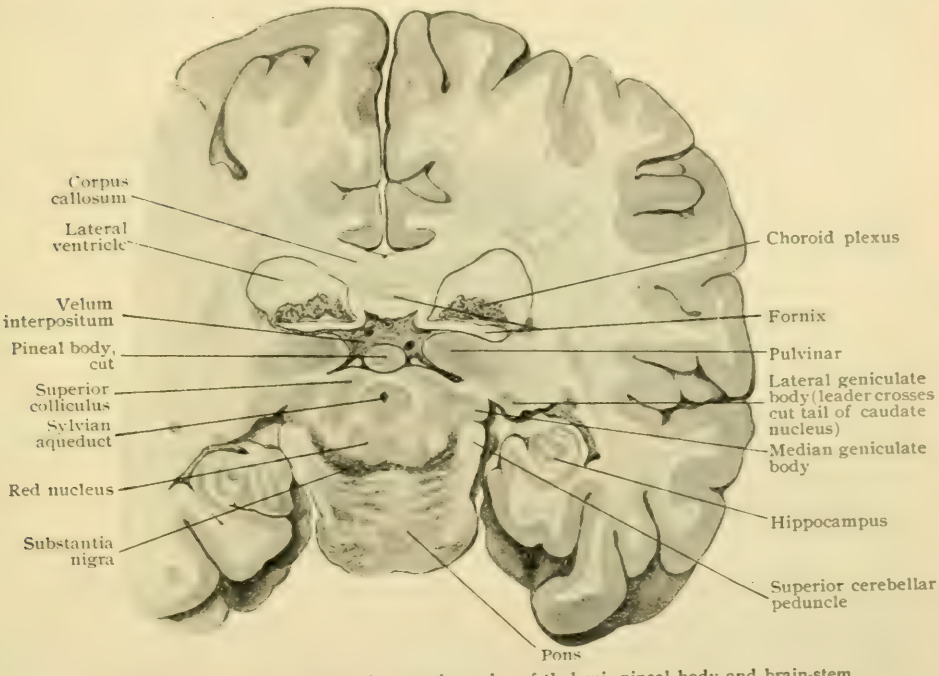
The **lateral geniculate bodies,** (**corpora geniculata laterales**), one on each side, are two fusiform elevations, about 10 mm. in length and half as much in width, which project from the outer and under surface of the posterior part of the thalamus (Fig. 958). They are so buried within the thalamus that they are much less distinct than the median geniculate bodies. In front they receive the outer division of the optic tracts, while behind they are connected by the superior brachia with the superior corpora quadrigemina. In structure the lateral geniculate body consists of alternating layers of white and gray matter. The former, somewhat thinner than the gray substance, is, to a large measure, the optic fibres, many of which end around the cells within the gray laminæ. Other fibres of the optic tract continue without interruption into the superior brachium and so to the upper colliculus, while a certain number end within the thalamus, and in their course over the surface of the latter take part in the production of the stratum zonale (page 1118). From many of the cells within the geniculate body, fibres proceed by way of the optic radiations to the cerebral cortex.

Then, too, many corticifugal fibres course in the opposite direction as the axones of the cortical cells, and end in relation to the geniculate neurones, thus establishing a double relation between the lateral geniculate body and the occipital cortex.

The Hypothalamus.—Although, strictly regarded according to its developmental relations, the diencephalon claims only the posterior or mammillary part of the hypothalamus, it is desirable to consider at this time the derivations of the entire hypothalamic subdivision of the fore-brain. Under the above heading will be described, therefore, the structures lying within or forming the floor and the anterior wall of the third ventricle, including the subthalamic region.

The **subthalamic region** in its developmental relations stands, as it were, as a link connecting the diencephalon and the mid-brain. The subthalamic region is the upward prolongation of the tegmentum of the cerebral peduncles and occupies, on each side of the mid-line, the triangular area between the thalamus above and the internal capsule and its continuation, the crusta of the peduncle, below (Fig. 974). It is insepa-

FIG. 975.



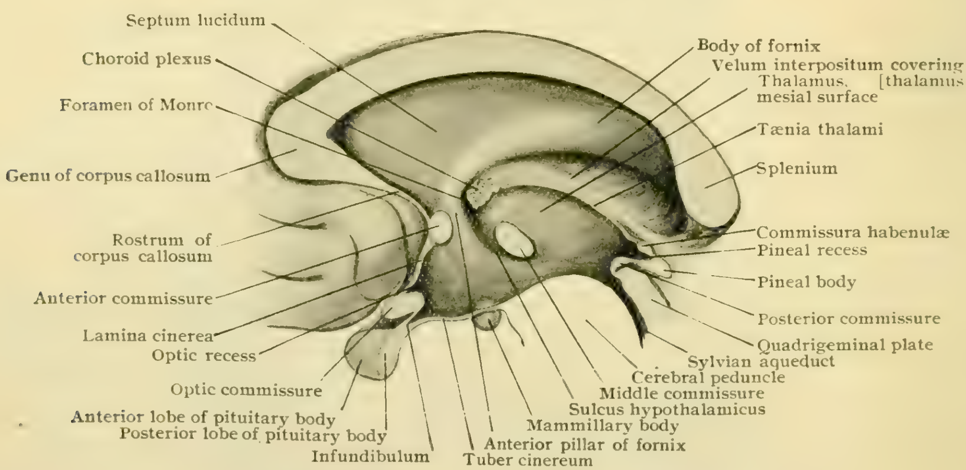
Frontal section of brain passing through posterior poles of thalami, pineal body and brain-stem.

rably blended with the ventral surface of the thalamus, which thus obliquely overlies the termination of the tegmental or sensory portion of the cerebral stalk. Through this area the important thalamocipetal paths of the fillet and of the superior cerebellar peduncles reach the thalamus, and within it are seen the upper extremities of the chief ganglia of the mid-brain, the *substantia nigra* and the *red nucleus*, and a new mass of gray matter, the *corpus subthalamicum*. The **substantia nigra** presents the same characteristics here as in the peduncle, being conspicuously dark and overlying the crustal fibres. As it ascends, it decreases in bulk from within outward until, at the level of the mammillary body, the substantia nigra is no longer recognizable. The connections of the cells within the substantia nigra are imperfectly understood, but it is probable that they receive many fibres from the caudate nucleus and the putamen and, perhaps, also from the frontal cortical areas. From the cells, on the other hand, fibres pass into the tegmentum and into the crusta and thence to lower levels. According to Bechterew, some fibres join the fillet-tract and thus reach the superior quadrigeminal bodies. At first the **red nucleus** is a very prominent feature in frontal sections of the subthalamic region (Fig. 970), appearing

as a circular area of gray matter enclosed by a zone of cerebello-thalamic fibres; farther forward it, too, gradually diminishes and disappears at a level somewhat behind that of the corpora mammillaria. The connections of the red nucleus have been considered in connection with the superior cerebellar peduncle (page 1095); suffice it here to recall its twofold significance as an interruption station for many of the cerebello-rubro-spinal and for the cerebro-rubro-spinal tracts.

The **corpus subthalamicum** (**nucleus hypothalamicus**), or *nucleus of Luys*, is a mass of deeply tinted gray matter peculiar to the subthalamic region and unrepresented in the mid-brain. It appears in cross-section (Fig. 970) as a small biconvex area, immediately dorsal to the tract of crustal fibres and lateral to the red nucleus and the substantia nigra. As the latter diminishes, the subthalamic nucleus expands to take its place and, where fully represented, measures from 3–4 mm. in thickness and from 10–12 mm. in its longest diameter, and extends superiorly considerably beyond the level of the red nucleus. Histologically the subthalamic body is distinguished by a dense net-work of fine medullated nerve-fibres, enclosing pigmented multipolar nerve-cells of medium size, and by an unusually close mesh-work of capillary blood-vessels. The dorsal surface of the nucleus is defined by the overlying lateral part of the **field**

FIG. 976.



Right lateral wall of third ventricle; velum interpositum covers superior surface of thalamus.

of Forel, as the stream of fibres passing between the red nucleus and the thalamus and the internal capsule is called. From the ventral surface of the nucleus, fibres pierce the adjacent crusta and join the ansa lenticularis to gain, probably, the globus pallidus; other perforating fibres perhaps connect the subthalamic body with Meynert's and Gudden's commissures (Obersteiner). The ventro-medial ends of the bodies of the two sides are connected by a bridge, the **commissura hypothalamica**, which traverses the floor of the third ventricle above the mammillary bodies. In addition to connecting the two subthalamic nuclei, the commissure contains decussating fibres from the anterior pillars of the fornix and, according to Edinger, probably fibres from the fore-end of the posterior longitudinal fasciculus.

The **corpora mammillaria** (**corpora mamillaria**), also called the *corpora albicantia*, are two hemispherical elevations, about 5 mm. in diameter, which lie close to the mid-line within the interpeduncular space on the basal surface of the brain (Fig. 993). They are almost but not quite in contact, being separated by a narrow interval which immediately behind the little bodies deepens into the anterior recess marking the front end of the shallow median furrow that grooves the posterior perforated substance. The posterior surfaces of the mammillary bodies indicate the anterior limit of the ventral surface of the mid-brain. When examined in section (Fig. 970),

each body is seen to be composed of an outer layer of white matter enclosing a core of gray substance, known collectively as the **nucleus mammillaris**. The latter is subdivided into a medial and lateral part by fibres from the downward arching anterior pillar of the fornix, which penetrate the gray matter as well as invest to a large extent its exterior. Only a part of (1) the *fornix fibres*, however, end directly in the mammillary nuclei, since some pass above and behind the ganglion to gain the hypothalamic commissure (page 1128) and, after decussation, to end in the mammillary body of the opposite side. From the dorsal part of the medial nucleus, distinguished from the lateral one by its larger nerve-cells, emerges a distinct and compact bundle of fibers (Fig. 967), which on clearing the nucleus, separates into two strands. One of these, known as (2) the *mammillo-thalamic tract*, or the *bundle of Vicq d'Azyr*, courses upward and forward, and ends within the anterior nucleus of the thalamus; in this manner it completes the paths by which the cortical olfactory centres within the hippocampus major are connected (by way of the fimbria, body and anterior pillar of the fornix and the mammillo-thalamic strand) with the thalamus (Fig. 1049). That fibres pass between the latter and the mammillary nucleus in both directions, is shown by the fact that destruction of either of these centres is followed in turn by ascending or descending degeneration of the fibres. (3) The other part of the bundle issuing from the mammillary nucleus arches backward and downward and, as the *mammillo-tegmental tract*, is traceable into the tegmentum of the mid-brain to the vicinity of the inferior colliculus. (4) Under the name, *pedunculus corporis mammillaris*, another mammillo-tegmental tract is described. This strand springs from the lateral mammillary nucleus, and, coursing backward and downward along the medial margin of the crusta, enters the tegmentum. Its destination is uncertain, but according to Kölliker the tract probably ends in the central gray matter surrounding the Sylvian aqueduct in proximity with the trochlear nucleus. Other, but much less well established, strands have been described by Lenhossék as proceeding forward from the peripheral layer of the mammillary body over the tuber cinereum. Concerning their further course little is known with certainty.

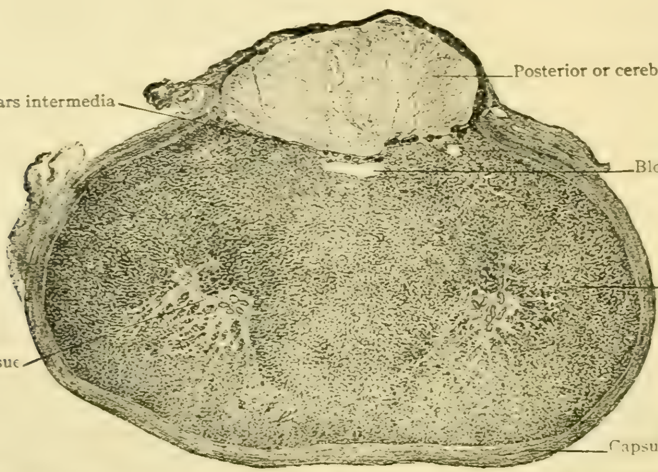
The **tuber cinereum** is the first of a series of median outpouchings which model the thin sheet of gray matter constituting the floor and the anterior wall of the third ventricle and belong to the pars optica of the hypothalamus. As seen from the exterior (Fig. 993), the tuber cinereum is a median elevation placed between the mammillary bodies behind and the optic chiasm in front, and the cerebral peduncles and the optic tracts at the sides. Together with the infundibulum, it forms the most dependent part of the third ventricle and consists of a thin layer of gray matter, less than 1.5 mm. thick, that is continued forward as the attenuated extension of the important sheet found within the mid-brain and fourth ventricle. In addition to the fibre-strands coming from the mammillary bodies noted by Lenhossék, this investigator and Kölliker credit the tuber cinereum with possessing small paired composite ganglia, the *nuclei tuberis* and the *nuclei supraoptici* of Kölliker. Concerning their connections nothing is definitely known. The anterior part of the tuber, immediately behind the optic chiasm, descends abruptly and somewhat forward to form a funnel-shaped stalk, the **infundibulum**, to whose lower end or apex is attached the posterior lobe of the pituitary body (Fig. 976). Although in the very young child the infundibulum retains to some extent its original character as a hollow outgrowth from the ventricle, in the mature subject this cavity, the **recessus infundibuli**, has mostly disappeared and the stalk is solid, save for a slight diverticulum within its upper and widest part.

The posterior part of the tuber cinereum, between the root of the infundibulum and the mammillary bodies, exhibits occasionally in the adult brain, and almost constantly in that of the fœtus, a small rounded median projection, flanked on each side by a slight elevation. To this modelling Retzius has applied the name, *eminentia saccularis* in recognition of its similarity to the evagination (saccus vasculosus) found in fishes. The eminence encloses a shallow pouch, *recessus saccularis*, which opens into the third ventricle.

The **pituitary body** (**hypophysis cerebri**) is attached to the dependent tip of the infundibulum, and, closely invested by a loose sheath of connective tissue, hangs

within the pituitary fossa on the base of the skull, just in advance of the dorsum sellæ (Fig. 996). Above, the fossa is closed by a special partition of dura, the *diaphragma sellæ*, through an opening in which the infundibulum passes to the mushroom-shaped organ. The pituitary body consists of two principal parts, of which the so-called **anterior lobe** is much the larger and of a darker grayish red color. The boundary between the anterior and posterior lobes is occupied by a zone of modified glandular tissue, the **pars intermedia,** which extends for a variable distance along the ventral surface of the posterior lobe towards the infundibulum. The two lobes are not only distinct as to structure and probably function, but are developed from entirely different regions. The anterior lobe is formed as an outgrowth from the oral diverticulum, while the posterior lobe first appears as a ventral evagination from the diencephalon (Fig. 1532). The anterior lobe, glandular in character, has been described in connection with the Accessory Organs of Nutrition (page 1806) and, therefore, calls for no further consideration in this place.

FIG. 977.



Transverse section of pituitary body, showing relation of anterior (oral) and posterior (cerebral) lobes. × 7.

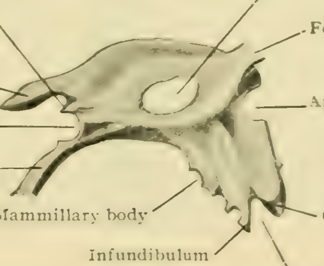
The **posterior lobe** of the pituitary body is lighter in color and softer in consistence and directly attached to the floor of the third ventricle by means of its stalk, the infundibulum. During the early stages of its development, this lobe is represented by a tubular outgrowth whose walls partake of the general character of the adjacent brain-vesicle. Later the lumen within the lower end of the diverticulum disappears in consequence of thickening and approximation of its walls, a funnel-shaped recess of variable depth within the infundibulum alone remaining. In the adult condition, the posterior or cerebral lobe retains few histological features suggesting its nervous origin. Of the demonstrable interlacing fibres, with fusiform enlargements and elongated nuclei, none can be identified as nerve-fibres, while of the numerous cells which the lobule contains, only a few of large size and pigmented cytoplasm uncertainly resemble nervous elements. With the exception of possibly neurogliar cells, the existence of definite nervous tissue within the cerebral lobe of the mature human hypophysis is doubtful.

The **optic tracts** and **commissure** are elsewhere described (page 1223), suffice it at this place to mention their relation to the interpeduncular structures. The optic tracts diverge backward and wind around the ventral surface of the cerebral peduncles (Fig. 993). Their medial ends are fused into a transversely flattened white band, the optic commissure or chiasm. The latter is connected with the front surface of the tuber cinereum, whilst above the chiasm the anterior wall of the ventricle consists of a delicate sheet of gray matter, the **lamina cinerea** (**lamina terminalis**). This structure lies in the mid-line, passes almost vertically upward, with a slight forwardly directed curve, and becomes continuous with the rostrum of the corpus

callosum. Just before meeting the latter, the lamina passes in front of the anterior commissure of the brain (Fig. 976).

The Third Ventricle.—The third ventricle (ventriculus tertius cerebri) is the narrow cleft-like space that separates the medial surfaces of the thalami (Fig. 966). It is somewhat broader behind and much deeper in front, where it comes into close relation with the exterior of the brain, the interpeduncular lamina alone intervening. Seen from the side, as in mesial sagittal sections (Fig. 996), the outline of the ventricle is irregularly comet-shaped, with the broader end above and behind and the blunted point directed downward and forward (Fig. 978). Behind, it communicates with the Sylvian aqueduct, and through this canal indirectly with the fourth ventricle; anteriorly it connects with the two lateral ventricles by means of the foramina of Monro. Its sagittal diameter, measured between the anterior commissure and the base of the pineal body, is approximately 2.5 cm. The **lateral wall** of the ventricle (Fig. 976) is formed chiefly by that part of the thalamus which lies below the level of the tænia thalami. On this surface, slightly in advance of the middle, is seen the small oval field of the *middle commissure*, and in front of this the downward curving elevation produced by the anterior pillar of the fornix. Between the latter and the prominent anterior tubercle of the thalamus lies the **foramen of Monro** (foramen interventriculare), which establishes communication between the third and the cor-

FIG. 978.



Cast of third ventricle, viewed from the side. × ⅘. (*Retzius.*)

responding lateral ventricle, and transmits the trunk formed by the union of the vein of the corpus striatum and the choroid vein. A shallow furrow on the ventricular wall, the **sulcus hypothalamicus** leads from the foramen backward and somewhat downward (Fig. 976). It is of importance as indicating, even in the adult brain, the demarcation between the thalamencephalon and the hypothalamus—parts derived respectively from the dorsal and ventral zones of the embryonic brain-vesicle.

The **roof** of the ventricle extends from the foramina of Monro, bounded above and in front by the arching pillars of the fornix, to the pineal body behind, over which it pouches out into the *suprapineal recess*, as the little diverticulum overlying the body is termed. The immediate and morphological roof consists of the delicate ependymal layer, which is attached to the tænia thalami on each side and, stretching across the interthalamic cleft, closes in the ventricle. The ependymal layer, however, is backed by a vascular fold of pia mater, which, in conjunction with the epithelial layer, constitutes the *velum interpositum*. This structure is more fully described in connection with the lateral ventricles (page 1162); but its relation to the third ventricle finds appropriate mention at this place. As in the roof of the fourth ventricle and in the lateral ventricles, so in the third does the vascular tissue of the pia mater invaginate the ependymal layer to form vascular fringes which project into the ventricle (Fig. 974). A double line of such invaginations hangs from the roof of the third ventricle and constitutes the *choroid plexus* of that space. Since the ependyma everywhere covers these pial processes, it is evident that the fringes are, strictly regarded, outside the ventricle and excluded by the continuous layer of the epithelium.

The posterior wall of the third ventricle is very short and includes the base of the pineal body, with the opening into the minute pineal recess, the posterior commissure and the orifice leading into the Sylvian aqueduct. The **floor** slopes rapidly downward and forward (Fig. 976) and comprises a small part of the tegmentum of the cerebral peduncles, the posterior perforated substance, the mammillary bodies, and the tuber cinereum with the infundibulum — structures already described and included within the interpeduncular area on the base of the brain. Corresponding with the position of the superficial elevation, the ventricle exhibits the diverticulum of the infundibulum. The optic chiasm marks the anterior limit of the floor and the beginning of the anterior wall. Immediately above the chiasm the **anterior wall** exhibits a diverticulum, the *optic recess*, from which the lamina cinerea ascends to join the rostrum of the corpus callosum, in its course passing close to and in front of the anterior commissure. The latter structure shows on the front wall of the

FIG. 979.

Portion of frontal section of brain passing through foramina of Monro, showing anterior wall of third ventricle modelled by anterior commissure and pillars of fornix.

ventricle as a transverse ridge between the descending and slightly diverging anterior pillars of the fornix (Fig. 979). Although distinctly modelling the ventricular walls, all of these bands are excluded from the ventricle by its ependymal lining.

THE TELENCEPHALON.

The telencephalon, or *end-brain*, consists of two fundamental parts, the **hemisphærium** and the **pars optica hypothalami**. The latter includes: (1) the *lamina cinerea (terminalis)*, (2) the *optic commissure*, (3) the *tuber cinereum* and (4) the *pituitary body*, all of which have been already considered, as a matter of convenience, in connection with the diencephalon and the third ventricle. The hemisphere comprises: (1) the *pallium*, (2) the *rhinencephalon*, and (3) the *corpus striatum*. The first of these subdivisions undergoes such enormous development in the anthropoid apes and in man, that the pallium becomes the dominating factor and, expanding upward, laterally and backward as the great cerebral mantle, not only forms the chief bulk of the cerebrum, but overlies the derivatives of the other brain-segments to such an extent that these parts are to a large measure covered and deposed from their primary position on the free dorsal surface of the brain. In consequence in man, in whom the pallium reaches its highest development, the thalami, corpora quadrigemina and the cerebellum are masked by the hemispheres and occupy topographically a dependent position. The *rhinencephalon*, on the contrary, is in man only feebly developed and rudimentary in comparison with the conspicuous and bulky corresponding structures possessed by animals in which the sense of smell is highly developed. The *corpus striatum*, consisting of two large masses of gray

matter, the *caudate* and the *lenticular nucleus*, represents the internal nucleus of the end-brain. Certain commissural structures, as the *corpus callosum*, the *anterior commissure* and the *fornix* are to be regarded as secondary and as serving to connect the halves of the great brain. The immediate free or outer surface of the pallium is everywhere formed by a thin peripheral layer of *cortical gray matter*, which, as an unbroken sheet, clothes the various ridges and intervening furrows—the *convolutions* and *fissures*—which model the exterior of the cerebrum and provide the necessary extent of surface. Beneath the cortical gray substance lies the *white matter*, which constitutes the bulk of the hemisphere and consists of the tracts of nerve-fibres passing to and from the cortex, as well as of those connecting the various regions of the cortex with one another. Embedded within the core of white matter and lying much nearer the basal than the superior surface of the hemisphere (Fig. 1009), the corpus striatum is closely related to the ventricular cavity by means of the caudate nucleus on the one hand, and to the cortical gray matter by the lenticular nucleus on the other. In view of the rudimentary condition of the rhinencephalon and the over-shadowing development of the pallium in man, it is usual and convenient to regard most of the parts derived from the telencephalon as belonging to the hemispheres, the latter term being used in a less restricted sense than warranted by a precise interpretation of its developmental significance.

The Cerebral Hemispheres.

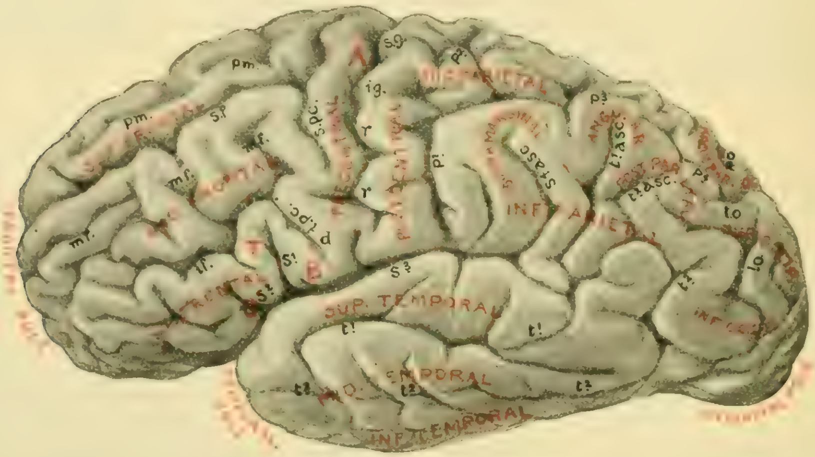
Viewed from above, the human brain presents an ovoid form, the narrower end being directed forward and the broader backward, the greatest width corresponding with the parietal eminences (Fig. 984). The convex surface formed by the hemispheres is divided by a deep median sagittal cleft, the **longitudinal fissure** (**fissura longitudinalis cerebri**), that, for a distance less than one-third of its length anteriorly and more than one-third posteriorly, completely separates the hemispheres. In its middle third or more, the fissure is interrupted at a depth of about 3.5 cm. by the arched upper surface of the *corpus callosum*, the chief connection between the hemispheres. The upper and back part of the longitudinal fissure, throughout its length, is occupied by the sickle-shaped mesial fold of dura mater, the *falx cerebri*, which incompletely subdivides the space occupied by the cerebrum into two compartments. Under the name, **transverse fissure** (**fissura transversa cerebri**), is sometimes described the deep cleft which separates the postero-inferior surface of the hemisphere from the cerebellum, the corpora quadrigemina and the pineal body. This cleft, so evident after the brain has been removed from the skull, when the parts are *in situ* is filled behind by the *tentorium cerebelli* and in front by a fold of pia.

The hemispheres are advantageously studied after being separated from each other by sagittal section, and from the brain-stem by cutting across the mid-brain. When examined after such isolation, especially when hardened before removal from the skull, each hemisphere presents a dorso-lateral, a mesial and an inferior surface. The **dorso-lateral surface** (Fig. 980) is convex both from before backward and from above downward and closely conforms to the opposed inner surface of the cranial vault. The **mesial surface** (Fig. 987) is flat and vertical and bounds the longitudinal fissure. It is in contact with the sagittal fold of dura, the falx cerebri, except in front and below where the partition is narrow; here the mesial surfaces of the hemispheres, covered of course by the pia and arachnoid, lie in apposition. The **inferior surface** (Fig. 989) is irregular, its approximate anterior third resting in the anterior cerebral fossa of the cranial floor, the middle third in the lateral part of the middle fossa, whilst the posterior third is supported by the upper aspect of the tentorium, which separates it from the subjacent cerebellum. At the juncture of its anterior and middle thirds, the inferior surface of the hemisphere is crossed transversely, from within outward, by the stem of the Sylvian fissure and thus subdivided into an anterior and a posterior tract. The former and smaller, known as the *orbital area*, rests upon the orbital plate of the frontal bone and is modelled by this convex bony shelf into a corresponding slight concavity from side to side. The tract behind the deep Sylvian cleft is at first convex

and rounded, as it lies within the middle fossa, but traced backward it passes insensibly into the *tentorial area*, supported by the tentorium cerebelli. This area is concave from before backward and directed inward as well as downward, in correspondence with the characteristic curvature of the tent-like dural septum.

The borders separating the surfaces of the hemisphere are the dorso-mesial, the infero-lateral and the infero-mesial. The **dorso-mesial border** intervenes between the mesial and lateral surfaces and, therefore, follows the arched contour of the hemisphere beneath the vaulted calvaria. The **infero-lateral border,** between the lateral and inferior surfaces, is better defined in front, where it separates the orbital area from the external surface as the arched *superciliary border* (Cunningham), than behind, where it is so rounded off as to scarcely be recognizable as a distinct margin. The **infero-mesial border** intervenes between the mesial and the inferior surface of the hemisphere. It is well marked in front, where it limits the orbital area mesially, and again behind, where it corresponds to the line of juncture between

FIG. 980.



Lateral aspect of left cerebral hemisphere; dorso-median surface is somewhat foreshortened; red lines indicate boundaries separating parietal, temporal and occipital lobes; *r*, Rolandic fissure; *s. g.*, *i. g.*, its superior and inferior genu; S^1, S^2, S^3, S^4 *asc.*, vertical, horizontal, posterior and ascending limbs of Sylvian fissure; *i. p. c.*, *s. p. c.*, inferior and superior precentral; *sf.*, *if.*, superior and inferior frontal; *p. m.*, paramedian; *m. f.*, mid-frontal; *d.*, diagonal, here continuous with inferior precentral; p^1, p^2, p^3, p^4, inferior, superior, horizontal and occipital limbs of inter-parietal; *p. o.*, parieto-occipital; t^1, t^1 *asc.*, superior temporal and its upturned limb; t^2, t^2 *asc.*, middle temporal and its upturned limb; *t. o.*, transverse occipital; *l. o.*, lateral occipital; *A.*, arm centre; *B. T. O.*, pars basalis, triangularis and orbitalis; *Arc. p.-o.*, arcus parieto-occipitalis.

the falx cerebri and the tentorium and marks the division between the mesial surface and the tentorial area. This margin has been designated the *internal occipital border* by Cunningham.

The extreme anterior end of the cerebral hemisphere is known as the **frontal pole** (**polus frontalis**), and the most projecting part of the posterior end as the **occipital pole** (**polus occipitalis**), while the tip of the subdivision of the hemisphere which projects below the Sylvian fissure constitutes the **temporal pole** (**polus temporalis**). A short distance behind the latter, the inferior surface exhibits a well defined *petrosal depression* (**impressio petrosa**); this is caused by the elevation crossing the petrous portion of the temporal bone which corresponds to the position of the superior semicircular canal. Under favorable conditions of hardening, the infero-mesial aspect of the occipital pole sometimes displays a broad shallow groove which marks the commencement of the lateral sinus. The groove is usually better marked on the right side than on the left, in accordance with the larger size of the right sinus as commonly found; occasionally these relations are reversed, and frequently no groove is recognizable on the side of the smaller sinus. In brains hardened *in situ*, the gently arching curve of the hind-half of the infero-lateral border of the hemisphere is interrupted by a more or less evident indentation, the **preoccipital notch** (**incisura praeoccipitalis**), at a point about 3.75 cm. (1½ in.) in front of the occipital pole (Fig. 980). This notch, prominent in the child but later variable in

its distinctness, is produced by a fold of dura over the parieto-mastoid suture and above the highest part of the lateral sinus (Cunningham). It is of importance in the topography of the brain, since it is often taken as the lower limit of the *parieto-occipital line*, establishing the conventional division on the lateral surface of the hemisphere between the parietal and occipital lobes (page 1143).

The complex modelling of the surface of the cerebral hemispheres, the characteristic feature of the human brain, is produced by the presence of irregular elevations, the **convolutions** or **gyri**, separated by the intervening furrows, the **fissures** or **sulci**. Although presenting many variations in the details of their arrangement, not only in different individuals but even in the hemispheres of the same brain, the convolutions and fissures of every normal human brain are grouped according to a general and definite plan to which the brain-patterns, whether elaborate or simple, in the main conform. The fissures differ greatly not only as to their depth as observed in the fully formed brain, but also as to their relation with the developing hemisphere, a very few, known as the **complete fissures**, involving the entire thickness of the wall of the cerebral vesicle and in consequence producing corresponding elevations on the internal surface of the ventricular cavities. Of such total sulci the most important permanent ones are: (1) the *hippocampal fissure*, which produces the projection known as the hippocampus major within the lateral ventricle; (2) the anterior part of the *calcarine fissure*, which gives rise to the calcar avis; and (3) the fore-part of the *collateral fissure*, which is responsible for the variable collateral eminence. The *choroidal* and the *parieto-occipital fissure* are also complete fissures of fœtal life, but give rise to invaginations which do not permanently model the ventricular walls. The remaining furrows merely impress the surface of the hemispheres and are termed **incomplete fissures**. Their depth varies, in some cases being only a few millimetres and in others as much as 2.5 cm., with an average of about 1 cm. The height of the convolutions usually exceeds their width, the latter, in turn, being commonly somewhat greater at the surface than at the bases of the gyri. It is evident, therefore, that the convoluted condition of the hemispheres provides a greatly increased area of cortical gray matter without unduly adding to the bulk of the brain, the extent of the sunken surface being estimated as twice that of the exposed. The larger and longer adjacent convolutions are frequently connected by short ridges, the **annectant gyri**, which have no place in the typical arrangement. They may cross the bottom of the intervening fissure and ordinarily be entirely hidden from view (**gyri profundi**); or they may be superficially placed (**gyri transitivi**) and materially add to the complexity of the surface configuration.

The cause and origin of the cerebral convolutions are still subjects for discussion. The fact, that at the time the fissures begin to appear, towards the end of the fifth fœtal month, the surface of the young brain is not in close contact with the cranial wall, disproves the assumption that the latter is directly responsible for the production of the fissures and convolutions. It is probable that the immediate cause of the surface modelling must be sought in the unequal growth and consequent localized tension which affect the hemispheres, excessive growth in the longitudinal axis resulting in transverse furrows, and that in the opposite axis producing fissures extending lengthwise. Whether the excessive expansion is caused by increase in the gray or white matter is uncertain, although local augmentation of the cortical gray substance is probably the more important factor. After the beginning of the eighth month, when the growing brain comes into contact with the cranial wall, the convolutions, which before were to a large extent unrestrained and therefore relatively broad and rounded, suffer compression, the results of which are seen in the flattening and closer packing of the gyri and the narrowing and deepening of the intervening fissures. By the end of fœtal life the salient features of the plan of arrangement have been established, although the final details of the brain-pattern are not acquired until sometime after birth.

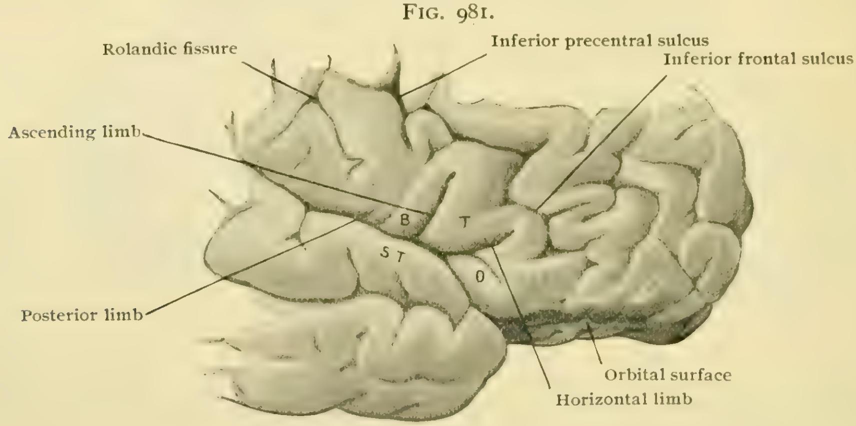
The Cerebral Lobes and Interlobar Fissures.—For the purposes of description and topography, the cerebral hemispheres are subdivided into more or less definite tracts, the **lobes**, by certain sulci, appropriately known as the **interlobar fissures**. With few exceptions, however, the lobes so defined have little fundamental importance, since their recognition is warranted by convenience and not by morphological significance, in most cases the conspicuous limiting sulci being of

secondary importance, while those of primary value are comparatively obscure in the fully formed human brain. The interlobar fissures, six in number, are: (1) the *fissure of Sylvius*, (2) the *central fissure*, (3) the *parieto-occipital fissure*, (4) the *collateral fissure*, (5) the *calloso-marginal fissure* and (6) the *limiting sulcus of Reil*.

The lobes marked off by these fissures with varying degrees of certainty are: (1) the *frontal*, (2) the *parietal*, (3) the *temporal*, (4) the *occipital*, (5) the *limbic*, and (6) the *insula*. An additional division, (7) the *olfactory lobe*, although of importance as representing the peripheral part of the rhinencephalon of osmatic animals (as those possessing the sense of smell in a high degree are called), is not related to the foregoing sulci and comprises the rudimentary olfactory bulb and tract and associated parts (page 1151). It will be of advantage to describe the interlobar fissures as preparatory to a detailed consideration of the lobes.

The **fissure of Sylvius** (**fissura cerebri lateralis**) is the most conspicuous fissure of the hemisphere. It begins on the inferior surface of the brain in a depression, the *vallecula Sylvii*, which opens out on the anterior perforated space. The first part of the fissure, its *stem*, passes horizontally outward to the lateral surface of the hemisphere, forming a deep cleft which separates the orbital area from the underlying temporal pole.

FIG. 981.



Portion of lateral surface of right hemisphere, showing ascending, horizontal and posterior limbs of Sylvian fissure radiating from Sylvian point. *B*, *T*, *O*, pars basalis, triangularis and orbitalis of inferior frontal gyrus: *ST*, superior temporal gyrus.

On reaching the surface at the *Sylvian point*, the fissure divides (Fig. 981) into (*a*) a short anterior horizontal branch, (*b*) a somewhat longer anterior ascending branch, and (*c*) a long posterior branch.

The *anterior horizontal branch* (**ramus anterior horizontalis**), about 2 cm. in length, extends forward into the inferior frontal gyrus parallel to and just above the infero-lateral border, and forms the lower limit of the pars triangularis (page 1141).

The *anterior ascending branch* (**ramus anterior ascendens**) passes upward and slightly forward into the hind-part of the inferior frontal convolution for a distance of about 3 cm. The frequently observed variations in the relation and arrangement of the anterior branches of the Sylvian fissure—the ascending and horizontal limbs in many cases arising from a common arm, sometimes being fused into a single sulcus, or again being absent—are due to atypical growth of the opercula, particularly of the frontal.

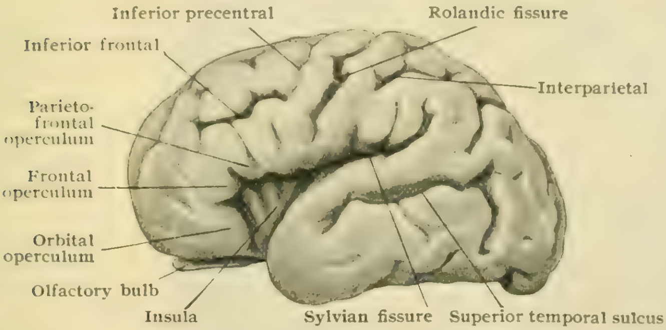
The *posterior branch* (**ramus posterior**), the main continuation of the fissure and about 8 cm. in length, is directed horizontally backward, with a slight inclination upward. It forms a very evident boundary between the anterior parts of the parietal and temporal lobes which it separates by a deep cleft that usually ends behind in an ascending limb surrounded by the angular gyrus (Fig. 980). Not infrequently the fissure ends by dividing into two short arms, one of which penetrates the parietal lobe while the other arches downward into the temporal lobe.

The form and relations of the fissure of Sylvius are so dependent upon the growth of the surrounding parts, that a sketch of the development of this region of the hemisphere is necessary for an understanding of the significance of this conspicuous sulcus. During the third fœtal month the lateral surface of the cerebral hemisphere presents a crescentic depressed area, the **fossa Sylvii**, whose floor corresponds to the *insula* or *island of Reil*. The latter is seen in the adult brain, on separating the margins of the Sylvian fissure, as a sunken area which is completely hidden by the overhanging parts, the **opercula insulæ**, of the surrounding lobes (Fig. 990). During the fifth month the former shallow crescentic Sylvian fossa gives place to a more definitely walled triangular depression, which, during the succeeding month, begins to be enclosed by the formation of the opercula. The details of this process have been carefully studied by Cunningham[1] and more recently by Retzius.[2] The opercula which bound the triangular fossa, named from the regions which contribute them and at first three in number, are the upper or *parieto-frontal*, the lower or *temporal*, and the anterior or *orbital*. The upper and lower walls first come in contact and thereby form the posterior limb of the Sylvian fissure. Later the angle between the upper and front walls of the fossa becomes modified and is finally obliterated by the appearance of a wedge-shaped projection, later the *frontal operculum*, which insinuates itself between the adjacent end of the parieto-frontal and the orbital opercula. The orbital and particularly the frontal operculum are late in their differentiation and growth, and not until towards the second year after birth do they come into apposition with each other and the remaining opercula to complete the curtain that overhangs the insula. Along with the closure of the front part of the Sylvian fossa, the differentiation of the anterior limbs of the fissure progresses, since upon the adequate growth of the frontal operculum depends the production of a distinct pars triangularis and of two separate anterior branches. Faulty development of this intermediate part of the opercular wall accounts for the Y or I form, as well as the occasional absence, of the anterior limbs.

FIG. 982.

Left hemisphere of brain of five months fœtus; three-fourths natural size.

FIG. 983.



Lateral surface of left hemisphere of eight months fœtus; insula is partly covered by opercula; three-fourths natural size. (*Retzius.*)

The **central fissure** (sulcus centralis), or **fissure of Rolando,** extends transversely across the upper half of the convex dorsal surface of the hemisphere and therefore, with the bordering precentral and postcentral convolutions, interrupts the general longitudinal course of the gyri and sulci. Bearing this peculiarity in mind, the fissure is readily identified even in brains exhibiting an elaborate and complex modelling. It begins above on the supero-mesial margin of the hemisphere, a short distance behind the middle of the border, and descends with a slight general forward obliquity to the vicinity of the posterior limit of the fissure of Sylvius, above whose mid-point it usually ends. Its upper extremity usually extends over the supero-mesial border of the hemisphere and, passing obliquely backward, cuts for a short distance into the marginal gyrus of the mesial surface (Fig. 987). Its lower extremity usually ends short of the Sylvian fissure, but occasionally (rarely) opens into this cleft. It constitutes a very definite boundary on the external surface of the hemisphere between the frontal and parietal lobes. Although passing obliquely downward and forward, the course of the central fissure is by no means straight

[1] Contribution to the Surface Anatomy of the Cerebral Hemispheres, Irish Academy, 1892.
[2] Das Menschenhirn, 1896.

owing to a marked angular backward projection of the substance of the precentral convolution, situated about the junction of the upper and middle thirds of the fissure. In consequence, the fissure presents in this part of its course a distinct curve, with the concavity directed forward, the upper and lower limits of this bend constituting the *superior* and the *inferior genu* respectively (Fig. 980). The cortical tissue filling this recess is of importance, since it represents the part of the precentral gyrus devoted to the motor centre for the arm. Below the inferior genu the fissure descends almost vertically, its lower end often bending slightly backward. The angle which the general direction of the central fissure makes with the mesial plane in the adult brain is on an average 71.7° (Cunningham), the *Rolandic angle*, as it is called, of the two sides subtending therefore about 143° (Fig. 984).

FIG. 984.

Superior aspect of cerebral hemispheres; *LF*, longitudinal fissure; *r.*, *r*, Rolandic fissure; *sg*, *ig*, its superior and inferior genu; *s. pc.*, superior precentral; *s. f*, *i. f*, superior and inferior frontal; *pm*, paramedian; p^1, p^2, p^3, p^4, inferior, superior, horizontal and occipital limbs of interparietal; *p-o*, parieto-occipital; *t.o.*, *l.o.*, transverse and lateral occipital; *Sasc*, ascending limb of Sylvian; $t^1asc.$, $t^2asc.$, ascending limbs of superior and middle temporal.

Since the central fissure is usually developed from two separate parts, a longer lower and a short upper (Cunningham, Retzius) which later become continuous, a deep annectant gyrus is generally found crossing the bottom of the sulcus at the junction of its upper and middle thirds. In exceptional cases the original separation is continued by the deep annectant gyrus maintaining its superficial relations, the adult fissure then being interrupted by the bridge which ordinarily is limited to the bottom of the cleft. As a variation of very great rarity, completed doubling of the central fissure has been observed.

The **parieto-occipital fissure** (fissura parieto-occipitalis) is seen chiefly on the mesial surface of the hemisphere (Fig. 987), where it appears as a deep cleft which extends from a point on the supero-mesial border of the hemisphere, about 4 cm. in front of the occipital pole, downward and forward. This inner part of the fissure,

the so-called *internal parieto-occipital fissure*, separates the mesial surfaces of the parietal and occipital lobes and ends below by joining the calcarine fissure, the two sulci together forming a ≻ whose posteriorly directed diverging limbs include a wedged-shaped portion of the occipital lobe known as the *cuneus*. The parieto-occipital fissure is continued without interruption across the upper margin of the hemisphere and onto the external surface for a short distance. This outer extension, usually only from 12–15 mm. in length, constitutes the *external parieto-occipital fissure* and terminates after its limited transverse course in a bowed convolution, the *arcus parieto-occipitalis*, which surrounds and separates its end from the occipital part of the interparietal fissure. Although sometimes ending in two short and somewhat open branches, the external limit of the parieto-occipital fissure is usually relatively inconspicuous; notwithstanding, the sulcus is of much importance as affording a readily recognized upper limit of the conventional boundary line between the occipital and the parietal and temporal lobes. In the fœtal brain the parieto-occipital sulcus produces a distinct invagination of the wall of the cerebrum and corresponds, therefore, to a complete fissure. In the adult brain, however, all trace of this infolding has disappeared in consequence of the growth and thickening of the ventricular wall which subsequently takes place (Cunningham).

The **collateral fissure** (**fissura collateralis**) is a well marked sulcus on the inferior surface of the hemisphere. It begins behind a little to the outer side of the occipital pole and extends forward, crossing the tentorial area parallel with, below and lateral to, the calcarine fissure, until opposite the posterior end of the corpus callosum, where it meets the hippocampal gyrus. It is then directed slightly outward, forming the lateral boundary of the last-named convolution, over the temporal area well toward the temporal pole, near which it either embraces or joins with a short curved furrow, the *incisura temporalis*, which, in conjunction with the collateral fissure, separates the lower or hippocampal part of the limbic lobe from the temporal lobe. According to Cunningham, the collateral fissure is at first represented by three distinct parts—a posterior or occipital, an intermediate and a temporal—which later become one continuous furrow. Of these three primary divisions, the intermediate, and usually also the temporal, are complete fissures, producing respectively the collateral protuberance and the collateral eminence seen in the lateral ventricle (page 1164). The occipital portion of the fissure is never complete and, therefore, does not give rise to any elevation.

The **calloso-marginal fissure** (**sulcus cinguli**) is the most conspicuous sulcus on the mesial surface of the hemisphere, where it appears as a curved furrow running above and concentric with the arched upper surface of the corpus callosum. It begins in front below the fore-end of this bridge, just above the anterior perforated space, sweeps around the genu of the corpus callosum and arches backward above the latter structure almost as far as the splenium, where it turns upward (**ramus marginalis**) and reaches the supero-mesial border of the hemisphere a short distance behind the overturned end of the Rolandic fissure. By its course the calloso-marginal sulcus marks off on the anterior two-thirds of the mesial surface of the hemisphere the marginal convolution of the frontal lobe from the callosal gyrus of the limbic lobe, the somewhat uncertain posterior boundary of the latter beyond the sulcus being indicated by the inconspicuous *postlimbic fissure*, which arches downward concentrically with the splenium. The frequent variations in the details of the calloso-marginal fissure depend upon irregularities in the arrangement and fusion of the three separate furrows by the union of which a continuous sulcus is formed.

The **limiting sulcus of Reil** (**sulcus circularis Reili**) is a shallow furrow that incompletely surrounds the insula and imperfectly separates this buried portion of the cerebral cortex from the deeper parts of the enclosing opercula. The sulcus consists of three parts—a *superior*, separating the island from the parietal and frontal lobes, an *anterior*, intervening in front between the insula and the frontal lobe, and a *posterior*, imperfectly separating the hind part of the island from the limbic lobe.

THE LOBES OF THE HEMISPHERES.

The Frontal Lobe.—The frontal lobe (**lobus frontalis**) is the largest of the subdivisions of the hemisphere and includes approximately one-third of the hemi-

cerebrum. It appears on each of the three aspects of the hemisphere and has, therefore, a dorso-lateral, a mesial and an inferior surface. On the *external surface* of the hemisphere it is bounded behind by the central fissure, which separates it from the parietal lobe, and below by the fore-part of the Sylvian fissure, which intervenes between it and the temporal lobe. On the *mesial surface* the frontal lobe includes an irregular ¬, marked off by the calloso-marginal sulcus, the longer upper limb ending behind the central fissure. On the *inferior surface* of the hemisphere, the frontal lobe includes the concave orbital area, bounded behind by the transversely directed stem of the Sylvian fissure, which sulcus thus separates it from the temporal lobe.

The principal *fissures on the dorso-lateral surface of the frontal lobe* are: (1) the inferior precentral, (2) the superior precentral, (3) the superior frontal and (4) the inferior frontal. The **inferior precentral sulcus** consists of a longer vertical and a short transverse limb and has a general ˥ or ⊤ form. The vertical limb begins above the fissure of Sylvius and in front of the central fissure and extends upward parallel to the latter and separated from it by the lower part of the precentral convolution. The horizontal limb passes obliquely forward and upward and cuts for a variable distance into the middle frontal convolution. Frequently the inferior precentral sulcus is directly continuous with the inferior frontal furrow; sometimes it opens below into the Sylvian fissure and above may join the superior.

FIG. 985.

Anterior aspect of cerebral hemispheres, hardened in skull; *sf*, *if*, superior and inferior frontal fissures; *pm.*, paramedian; *m.f*, mid-frontal; *f-m.*, fronto-marginal.

The **superior precentral sulcus** prolongs upward the anterior boundary of the precentral convolution. It lies parallel with the upper half of the Rolandic fissure, but does not usually, although sometimes reach the upper margin of the hemisphere. Almost constantly it receives the posterior end of the superior frontal sulcus with which it forms a ⊣ shaped furrow.

The **superior frontal sulcus** extends forward from the preceding fissure with a course which corresponds in general with the supero-mesial border of the hemisphere and thus marks off a longitudinal marginal tract, the superior frontal convolution. Anteriorly the superior frontal may join the median frontal sulcus, while its posterior end may incise the precentral convolution. Often the course of the fissure is interrupted by superficial annectant gyri which connect the adjacent borders of the upper and middle frontal convolutions.

The **inferior frontal sulcus** begins behind in the interval between the horizontal and vertical limbs of the inferior precentral furrow, or in confluence with one of these. In its general course it arches forward and downward towards the anterior or superciliary margin of the hemisphere and terminates a short distance behind this border by bifurcating into a transverse limb. The line of the fissure is often obscured by superficial annectant gyri and complicated by small secondary furrows which pass from it into the bordering middle and inferior frontal convolutions.

The *convolutions on the dorso-lateral surface of the frontal lobe* are the precentral, the superior frontal, the middle frontal and the inferior frontal.

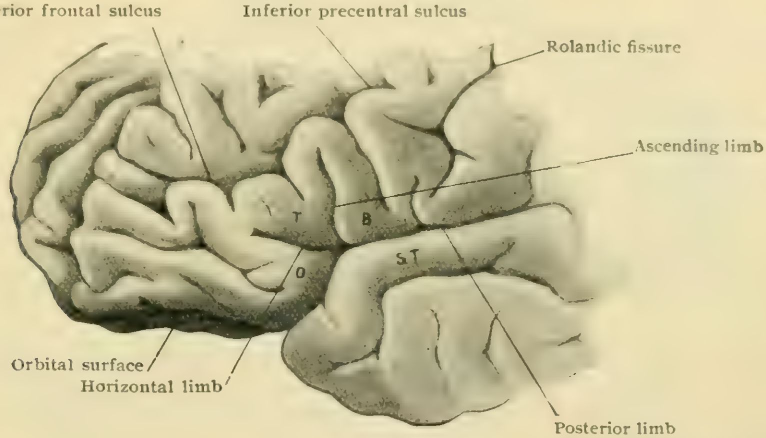
The **precentral gyrus** (gyrus centralis anterior), also known as the *ascending frontal*, is bounded behind by the central fissure and in front by the superior and inferior precentral sulci. Below it is limited by the Sylvian fissure, whilst its upper end is continuous with the paracentral lobule of the mesial surface. Anteriorly it is connected with all three frontal convolutions. A short distance above its middle, it sends backward a conspicuous projection, triangular or rounded in outline, which encroaches upon the postcentral gyrus and correspondingly modifies the line of the

Rolandic fissure. The observations of Mills and of Grünbaum and Sherrington emphasize the predominating importance of the precentral convolution as containing the important cortical motor areas (page 1211), the backward projection just noted containing the centres controlling the muscles of the upper extremity.

The **superior frontal gyrus** lies between the supero-mesial border of the hemisphere and the superior frontal sulcus. Since its course corresponds with the upper margin of the hemisphere, it is much longer than the other frontal convolutions on the external surface and reaches the frontal pole. It is continuous with the marginal gyrus, which, in fact, is only its mesial part. Behind, it joins the precentral convolution by a narrow bridge between the upper end of the precentral sulcus and that of a branch from the calloso-marginal fissure. The superior frontal convolution, notwithstanding its meagre width, is frequently imperfectly divided into an upper and a lower part by a series of shallow longitudinal furrows collectively termed the *paramedian sulcus.* The latter is regarded as a distinctive feature of the human brain, and is found relatively deep and well marked only in the brains of the higher races.

The **middle frontal gyrus,** the broadest of the three, extends forward parallel with the upper frontal convolution well towards the frontal pole. It is bounded

FIG. 986.



Portion of lateral surface of left hemisphere, showing pars basalis (B), triangularis (T) and orbitalis (O) of inferior frontal gyrus, known as Broca's convolution; $ST.$, superior temporal gyrus.

above and below by the superior and the inferior frontal sulcus and, in man and the anthropoid apes, is almost constantly subdivided into an upper and a lower sublower subdivision by the *mid-frontal sulcus* (**sulcus frontalis medius**). The latter is often broken by annectant gyri into two or more pieces and in front usually bifurcates to form the *fronto-marginal sulcus* (**sulcus transversus anterior**), which runs across the hemisphere a short distance above the superciliary margin.

The **inferior frontal gyrus,** the shortest of the three, lies below the inferior frontal sulcus and arches forward and downward around the anterior limbs of the Sylvian fissure. Below and behind it is connected with the lower end of the precentral convolution by a narrow bridge enclosing the lower end of the inferior precentral sulcus. By the ascending and horizontal limbs of the Sylvian fissure the inferior frontal gyrus is incompletely divided into three portions—the *pars basalis,* the *pars triangularis* and the *pars orbitalis* (Fig. 986). The **pars basalis** (**pars opercularis**) occupies the posterior part of the convolution and lies between the inferior precentral sulcus and the ascending Sylvian limb. It forms the fore-part of the fronto-parietal operculum and is indented by an inconspicuous although constant furrow, the *sulcus diagonalis,* which extends obliquely downward and forward across the gyrus for a variable distance. Although usually distinct, the diagonal sulcus may join the inferior precentral (Fig. 986), the inferior frontal or the Sylvian fissure. The **pars triangularis** is the wedge-shaped tract included between the two limbs of the Sylvian fissure. Its base is directed upward and forward and its

apex towards the Sylvian point. The **pars orbitalis** lies below the horizontal limb and is continued around the margin of the hemisphere onto the orbital surface of the frontal lobe. It is evident, from the description of the boundaries of the Sylvian fissure already given (page 1137), that the preceding subdivisions of the inferior frontal gyrus correspond with certain of the opercula—the pars basalis with the anterior part of the fronto-parietal, the pars triangularis with the frontal and the pars orbitalis with the orbital operculum. The posterior extremity of the inferior frontal gyrus on the left side is known as *Broca's convolution* and has long been regarded as the centre for the movements for articulate speech, although the accuracy of this view has been questioned. According to Marie, Broca's convolution has no relation with speech, a conclusion, however, so far not convincingly supported. The convolution is sometimes better developed on the left than the right side of the brain, the pars triangularis particularly being increased. As previously noted, the development of this wedge—the frontal operculum—bears a direct relation to the degree of independence of the two anterior limbs of the Sylvian fissure.

The *mesial surface of the frontal lobe* (Fig. 987), includes only one convolution, the **marginal gyrus**, which lies between the dorso-mesial margin of the hemisphere and the calloso-marginal sulcus (page 1139), and by the latter is separated from the limbic lobe. It is ¬-shaped and directly continuous with the superior frontal gyrus above and with the gyrus rectus on the orbital surface below. Its posterior end is almost completely cut off from the rest of the gyrus by an ascending limb (**sulcus paracentralis**) from the calloso-marginal sulcus, the portion so isolated forming the front part of the **paracentral lobule**, which is bounded behind by the upturned end (**ramus marginalis**) of the calloso-marginal sulcus and contains, near its hind border, the termination of the fissure of Rolando. By means of an annectant convolution passing below the last-named furrow, the frontal part of the paracentral lobule is continuous with the part contributed by the parietal lobe. The middle of the marginal gyrus is often incompletely subdivided by a shallow longitudinal groove, the *mesial frontal sulcus*, into an upper and a lower tract, whilst its anterior and lower end is uncertainly cleft by two or three short downward curving furrows, the *sulci rostrales*.

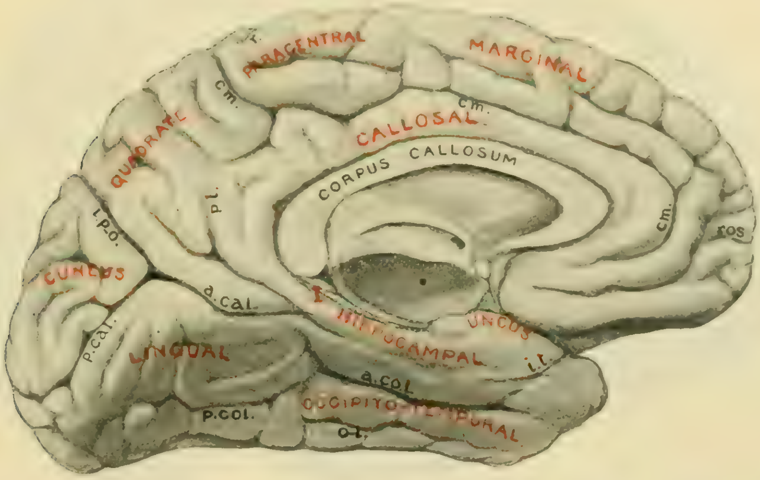
The *orbital surface of the frontal lobe* is marked by two fissures, the olfactory and the orbital and by three chief convolutions, the inner, the middle and the outer orbital. Although such division is convenient for the purposes of description, it must be remembered that these orbital gyri are not separate convolutions, but largely the inferior portions of the upper, middle and lower frontal convolutions of the outer surface of the lobe.

The **olfactory sulcus** lodges the olfactory bulb, tract and tubercle, and extends parallel with, or inclined somewhat towards the great longitudinal fissure. Its course being straight, the sulcus marks off a narrow strip, about 1 cm. in width, along the mesial border of the lobe. This area, although specially designated as the **gyrus rectus**, is only a part of the broader longitudinal tract which corresponds to the orbital surface of the superior frontal convolution.

The **orbital sulcus** includes a number of furrows whose arrangement is very variable, not only in different brains but often on the two sides of the same brain. In the disposition assumed as the typical one, which, however, is far from constant, the orbital sulcus consists of two *longitudinal limbs*, connected by a shorter *transverse* arm, the three furrows forming a common fissure which corresponds more or less closely with the letter H. In many cases, however, the sulcus more nearly resembles an X or K, or it may be still further modified by the presence of additional secondary grooves of variable number and length. Assuming the conventional H-form to exist, the orbital surface is divided into three longitudinal tracts, the **inner, middle** and **outer orbital gyri**, by the long limbs (**sulcus orbitalis internus et externus**). The inner tract is subdivided by the olfactory sulcus into the *gyrus rectus*, above mentioned, and an outer part, the *gyrus orbitalis internus* in the more restricted sense. The middle orbital gyrus is subdivided by the curved transverse limb (**sulcus orbitalis transversus**) into the *anterior* and the *posterior orbital gyrus*, which lie respectively in front and behind the transverse furrow. In many cases the latter curves outward and backward until it almost reaches the Sylvian fissure.

The Parietal Lobe.—This division includes a considerable part of the hemisphere and presents two surfaces, an external and a mesial. The external surface, much the more extensive and irregularly quadrilateral in outline, is bounded above, in front and partially below by well marked fissures, but behind and postero-inferiorly its limits from the occipital and temporal lobes are defined for the most part by imaginary lines. Its upper boundary corresponds with the supero-mesial border of the hemisphere; its anterior boundary is the central fissure, by which the parietal lobe is completely separated from the frontal except below, where the postcentral gyrus is continuous with the precentral by the bridge closing the lower end of the Rolandic fissure. Its posterior boundary, which separates the parietal from the occipital lobe, is largely conventional and indicated by a line drawn from the point where the parieto-occipital fissure cuts the upper margin of the hemisphere to an indentation, the preoccipital notch (page 1134), which grooves the infero-lateral border of the hemisphere at a point from 3.5–4 cm. in front of the occipital pole. Its inferior border, between the parietal and the temporal lobes, is definite where formed by the posterior limb of the Sylvian fissure. Beyond the upturned end of the latter,

FIG. 987.



Infero-mesial aspect of left cerebral hemisphere; *cm.*, calloso-marginal fissure; *ros.*, rostral; *r.*, overturned end of Rolandic; *p. l.*, post-limbic; *i. p-o.*, internal parieto-occipital; *p. cal.*, *a. cal.*, posterior and anterior calcarine, *p. col.*, *a. col.*, posterior and anterior collateral; *i. t.*, incisura temporalis or rhinial; *o-t.*, occipito-temporal.

the parietal and the temporal lobes are continuous and their separation is conventionally assumed to be made by an arbitrary line prolonged backward in the direction of the posterior limb of the Sylvian fissure until it meets the parieto-occipital line previously described.

The *external surface of the parietal lobe* is subdivided by a composite fissure, the interparietal sulcus, into three general tracts, the postcentral, the superior parietal and the inferior parietal gyrus.

The **interparietal sulcus,** especially described by Turner, starts in the antero-inferior angle of the lobe a short distance above the Sylvian fissure, with which it is rarely continuous, ascends for about an inch parallel with the central fissure, and then sweeps backward and slightly upward across the parietal into the occipital lobe. The interparietal sulcus is developed as four originally distinct parts, which in the fully formed brain, notwithstanding their usual fusion, are recognized as the inferior and the superior postcentral sulcus and the horizontal and occipital limbs (Cunningham).

The **inferior postcentral sulcus** lies behind and parallel with the lower part of the central fissure. Although in most cases continuous with either the superior postcentral sulcus (in 72 per cent. according to Retzius[1]), or with the horizontal limb

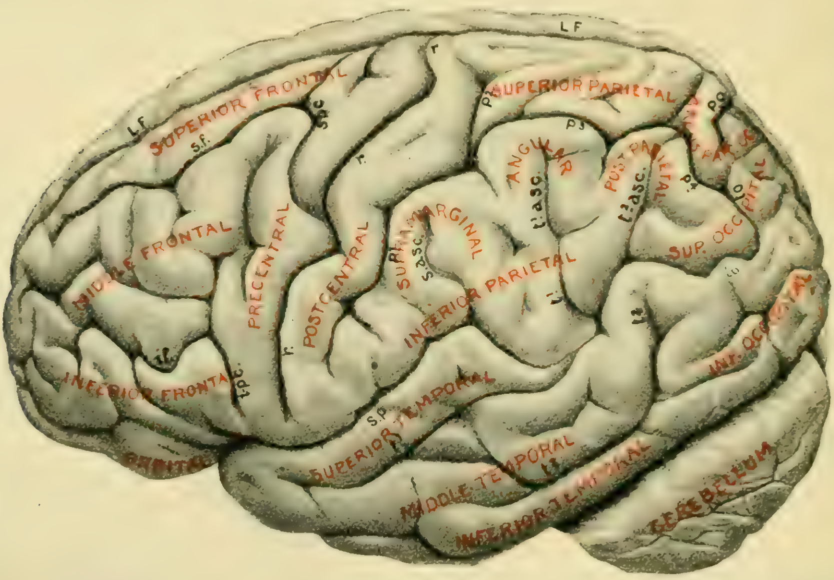
[1] Biologische Untersuchungen, VIII., 1898.

(66 per cent.), or with both (55 per cent.), the inferior limb may remain ununited (17 per cent.). When joined, the two limbs together form a continuous postcentral sulcus which parallels the fissure of Rolando and bounds the postcentral convolution behind. In rare instances the inferior postcentral sulcus opens below into the Sylvian fissure.

The **superior postcentral sulcus** lies behind and parallel with the upper part of the fissure of Rolando, gaining the superior margin of the hemisphere between the incisions of the Rolandic fissure and the upturned end of the calloso-marginal sulcus. Although in 59 per cent. of the brains studied by Retzius the fissure was confluent with the horizontal limb, in 24 per cent. it remained isolated.

The **horizontal limb** passes backward and slightly upward and separates the superior and inferior parietal convolutions from each other. It is usually continuous in front with one or the other or with both postcentral sulci and behind with the

FIG. 988.



Lateral aspect of left side of brain. *LF*, longitudinal fissure; *r., r., r.*, Rolandic fissure; *i. pc., s. pc.*, inferior and superior precentral; *sf., if.*, superior and inferior frontal; *Sp, S. asc.*, posterior and ascending limbs of Sylvian fissure; p^1, p^2, p^3, p^4, inferior, superior, horizontal and occipital limbs of interparietal; *p-o*, parieto-occipital; *t. o., l. o.*, transverse and lateral occipital; t^1, t^1*asc.*, superior temporal and its upturned limb; t^2, t^2*asc.*, middle temporal and its upturned limb.

posterior or occipital limb. As a rule it joins a continuous postcentral sulcus, in which case the three furrows form a ⊢ shaped fissure, which subdivides the parietal lobe into its three main convolutions.

The **occipital limb** is usually attached to the horizontal one and then directly prolongs the interparietal sulcus into the occipital lobe. Sometimes, however, it retains its original independence and is separated from the ramus horizontalis by a deep annectant gyrus. It is irregularly curved and marks the lower boundary of the gyrus, the arcus parieto-occipitalis, which receives the outer end of the parieto-occipital fissure. Beyond the line of this furrow, the sulcus lies in the occipital lobe and behind the arcus parieto-occipitalis ends by bifurcating into two widely divergent arms, which constitute the transverse occipital sulcus.

The chief *convolutions on the external surface of the parietal lobe* are three—the postcentral, the superior parietal and the inferior parietal.

The **postcentral gyrus**, also called the *ascending parietal*, forms the posterior wall of the fissure of Rolando, and itself is bounded behind by the postcentral sulcus, either by the continuous fissure or by its two divisions. The lower end of the gyrus is connected with the precentral convolution in front and with the inferior parietal one behind by the annectant gyri closing the lower ends of the central and postcen-

tral sulci respectively. Above, the convolution is continuous with the precentral lobule of the mesial surface between the terminations of the calloso-marginal and the Rolandic fissures. In its width and general oblique course across the hemisphere, the postcentral convolution strongly resembles the precentral gyrus and with the latter and the three associated sulci—the precentral, central and postcentral—forms a conspicuous feature in the modelling of the external surface of the hemisphere and affords a ready means of locating the Rolandic fissure.

The **superior parietal gyrus** is the triangular tract lying between superior postcentral sulcus, the horizontal limb of the interparietal sulcus and the supero-mesial border of the hemisphere. Behind, it is limited by the overturned outer end of the parieto-occipital fissure, around which, however, it is continuous with the occipital lobe by means of the curved convolution, the **arcus parieto-occipitalis.** Farther forward it is frequently deeply incised by an ascending branch from the interparietal sulcus. It is connected with the postcentral gyrus around the upper end of the superior postcentral sulcus and, in those cases in which the last-named sulcus fails to unite with outer segments of the interparietal fissure, additionally joins the postcentral gyrus about the inferior postcentral sulcus.

The **inferior parietal gyrus** is included between the curved interparietal sulcus and the conventional lower boundary of the lobe. Since only the front end of this boundary is defined by a groove, its greater part being the arbitrary line above described, it follows that behind the Sylvian fissure the inferior parietal convolution is continuous with the subjacent temporal gyri. The convolution is cut into from below by the upturned end of the Sylvian fissure and the terminations of the first and second temporal sulci and by these incisions is somewhat uncertainly subdivided into three parts, the supramarginal, the angular and the postparietal gyri (Fig. 988). The **supramarginal gyrus** arches around the upturned extremity of the Sylvian fissure. It lies behind and below the front part of the interparietal sulcus, around whose lower end it joins the postcentral gyrus, whilst below it is continuous with the superior temporal and behind with the angular gyrus. The **angular gyrus** surmounts the upwardly directed end of the superior temporal sulcus and below is prolonged into the superior and middle temporal convolutions. It is commonly imperfectly separated from the postparietal gyrus by a shallow furrow. The **postparietal gyrus** bends over the obliquely vertical extremity of the middle temporal sulcus and below joins the middle and inferior temporal convolutions. It lies approximately opposite the arcus parieto-occipitalis from which it is separated by the occipital branch of the interparietal sulcus.

The *mesial surface of the parietal lobe* includes an irregularly quadrate area extending from the internal limb of the parieto-occipital sulcus behind to the line of the Rolandic fissure in front; below it is imperfectly defined from the limbic lobe by the calloso-marginal sulcus, to a very slight extent, and its continuation, the post-limbic furrow. By far the greater part of this surface is embraced by the **quadrate lobule** or **precuneus,** an irregularly quadrilateral area (Fig. 987) limited in front by the upturned terminal limb of the calloso-marginal and behind by the parieto-occipital sulcus. The lobule, the mesial aspect of the superior parietal convolution, is usually marked by one or more furrows, the *precuneate sulci,* which incise the upper margin of the hemisphere and extend for a short distance onto the outer surface.

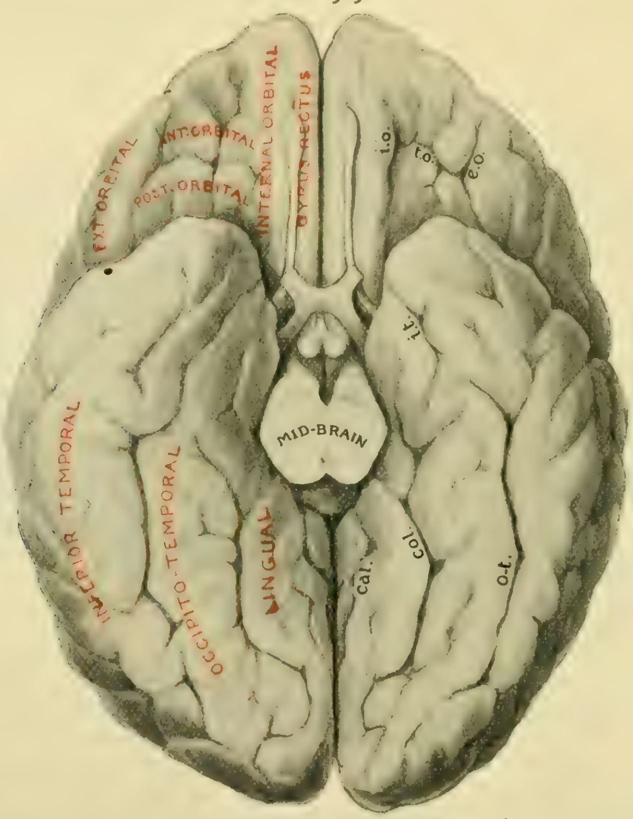
The Occipital Lobe.—The occipital lobe is pyramidal in form and includes the occipital pole and the adjacent parts of the hemisphere. It is represented on all of the aspects of the hemisphere and possesses, therefore, a lateral, a mesial and an inferior or tentorial surface. A well-marked occipital lobe is found only in the brain of man and of the anthropoid apes and is developed as a backward prolongation of the parietal and temporal lobes, from which, therefore, it is but imperfectly separated. On the mesial surface its extent is definitely limited by the internal parieto-occipital sulcus, by which it is cut off from the quadrate lobule or precuneus of the parietal lobe. On the lateral surface, on the contrary, it is continuous with the parietal and temporal lobes, its anterior boundary being arbitrary and indicated by the parieto-occipital line drawn from the overturned limit of the parieto-occipital sulcus above to the preoccipital notch below. On the inferior or tentorial aspect its demarcation is even more uncertain, the occipital, limbic and temporal lobes being here

directly continuous, and depends upon the recognition of an arbitrary line which may be drawn, as suggested by Cunningham, from the preoccipital notch on the infero-lateral border to the isthmus of the limbic lobe, just below the splenium of the corpus callosum.

The *external surface of the occipital lobe* is modelled by two well-defined fissures, the transverse occipital and the lateral occipital, and by two somewhat uncertain convolutions, the superior and the inferior occipital (Fig. 988).

The **transverse occipital sulcus** is, as above pointed out, the widely divergent terminal bifurcation of the interparietal fissure, whose last segment beyond the outer end of the parieto-occipital sulcus enters the occipital lobe to end in the manner just indicated.

FIG. 989.



Inferior aspect of cerebral hemispheres. *i.o.*, *t.o.*, *e.o.*, internal, transverse and external orbital fissures; *i.t.*, incisura temporalis; *cal.*, calcarine, *col.*, collateral; *o-t.*, occipito-temporal fissures.

The **lateral occipital sulcus** arches horizontally forward below the lower end of the preceding furrow, not infrequently dividing into an ascending and a descending limb.

The **superior** and **inferior occipital gyri** are the upper and lower areas into which the outer aspect of the occipital lobe is somewhat uncertainly subdivided by the lateral occipital sulcus. Secondary furrows and ridges often obscure the characteristic modelling of this surface, whilst annectant convolutions connect its gyri with the parietal and temporal lobes.

The *mesial surface of the occipital lobe* presents one sulcus, the calcarine fissure, a triangular tract, the cuneus, and part of the gyrus lingualis.

The **calcarine fissure** begins by a forked extremity, the longer lower limb of which incises the occipital pole in the impression made on the hemisphere by the lateral sinus. It then continues forward, slightly arched, a short distance above the border of the lobe formed by the junction of the falx cerebri and the tentorium, and

ends, after a short bend outward, by cutting into the limbic lobe just below the splenium of the corpus callosum (Fig. 987). This incision divides the posterior extremity of the hippocampal gyrus into a narrow upper tract, the *isthmus*, which links the gyrus with the callosal convolution, and a broader lower arm, which establishes continuity between the hippocampal and lingual gyri. A short distance in front of its middle, the calcarine fissure is joined by the lower end of the parieto-occipital sulcus, the two furrows forming a >-shaped sulcus, between whose diverging limbs lies the triangular cuneus. Although usually appearing as one continuous fissure, the parieto-occipital and calcarine sulci are incompletely separated by a deep annectant gyrus, which connects the cuneus with the limbic lobe. The calcarine fissure itself is subdivided by a second sunken gyrus into an anterior and a posterior part. The latter, the *posterior calcarine fissure*, is shorter and shallower than the front part and is not a total fissure. The other portion, the *anterior calcarine fissure*, is not only the deeper but completely invaginates the brain-wall, thereby giving rise to the elevation known as the calcar avis, seen on the inner boundary of the posterior horn of the lateral ventricle.

The **cuneus** forms the chief part of the mesial aspect of the occipital lobe. It is triangular in outline and lies between the parieto-occipital sulcus in front and the posterior limb of the calcarine fissure below, whilst above and behind it reaches the superior border of the hemisphere (Fig. 987). Its surface is frequently impressed by one or more shallow vertical furrows.

The **lingual gyrus**, also called the *infracalcarine*, is the irregular elongated tract bounded mesially and above by the calcarine fissure, and laterally and below by the collateral (Fig. 989). Its rounded hind-end lies in the occipital lobe, whilst its tapering and greatly narrowed front-end is continuous with the hippocampal convolution. The gyrus fits into the angle between the falx cerebri and the tentorium and therefore bears the internal occipital border of the hemisphere and appears on both the mesial and the tentorial surfaces. It is usually modelled by irregular shallow furrows which break up the larger tentorial aspect into uncertain secondary gyri.

The inferior or *tentorial surface of the occipital lobe* is continuous with the more extensive similar surface of the temporal lobe resting upon the tentorium. In addition to the tentorial part of the lingual gyrus, this aspect of the lobe is occupied by the posterior part of the **occipito-temporal gyrus.** The latter includes an irregular fusiform tract, bounded by the collateral fissure internally and by the inferior temporal sulcus laterally (Fig. 989). As expressed by its name, the occipito-temporal convolution belongs partly to the occipital and partly to the temporal lobe and extends from the occipital to the temporal pole. Its surface is broken by a number of irregularly disposed furrows which add to the uncertainty of its outer boundary.

The Temporal Lobe.—The temporal lobe includes the irregularly pyramidal division of the cerebral hemisphere, whose apex is lodged within the middle fossa of the skull and whose succeeding part forms the conspicuous dependent mass seen on the infero-lateral surface of the hemicerebrum. In front it is separated from the frontal lobe by the stem of the Sylvian fissure; above it is marked off from the parietal lobe by the posterior limb of the Sylvian fissure and the arbitrary line prolonged backward in the direction of this sulcus; externally and below it is defined by the infero-lateral border of the hemisphere; and mesially it is separated from the limbic lobe by the collateral fissure. Its posterior border, however, on both the lateral and the inferior (tentorial) surface is arbitrary and indicated by the lines already mentioned (pages 1143 and 1146) which afford the conventional demarcation between the occipital and temporal lobes.

The temporal lobe presents three surfaces, the convex *lateral*, the *inferior* (largely tentorial), and the buried *superior* or opercular. Of these the lateral and inferior are separated by a border so broad and rounded that the surfaces pass insensibly into each other. Its tip corresponds with the temporal pole of the hemisphere and underlies the posterior part of the orbital surface of the frontal lobe, which it partially masks.

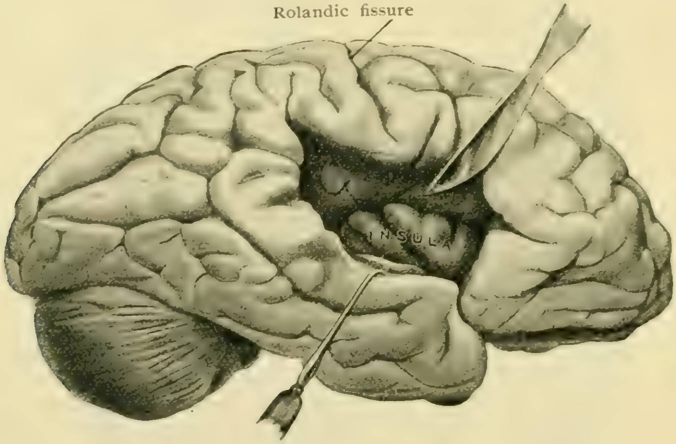
The *lateral surface of the temporal lobe* is modelled by two fissures, the superior and the middle temporal, and three convolutions, the superior, the middle and the

inferior temporal (Fig. 988), all of which correspond in the general direction of their course with the posterior limb of the Sylvian fissure and extend backward and slightly upward.

The **superior temporal sulcus**, also called the *parallel sulcus* in recognition of the similarity of its course with that of the posterior limb of the Sylvian fissure, is the first in the series of longitudinal furrows, the third of which appears not on the outer, but on the inferior aspect of the lobe. It begins near the temporal pole, runs parallel with the posterior limb of the Sylvian fissure and ends by cutting upward into the inferior parietal convolution, whose angular gyrus surrounds the upturned extremity of the sulcus.

The **middle temporal sulcus**, the second in the series, lies below the preceding fissure, whose direction in a general way it follows. It is, however, much less certainly marked and in most cases is not a continuous furrow, as is the superior sulcus, but broken by superficial annectant convolutions into a number of separate pieces, the exact sequence of which is often difficult to follow. The upturned end of the middle temporal sulcus cuts into the lower parietal convolution towards the posterior limb of the interparietal sulcus (Fig. 988) from which, however, it is separated by the arching postparietal gyrus.

FIG. 990.



Right cerebral hemisphere, with opercula displaced to expose island of Reil.

The **superior temporal gyrus** intervenes between the posterior limb of the Sylvian fissure and the superior temporal sulcus. Its lower end lies at the temporal pole, whilst above the tract is continuous with the supramarginal and angular gyri of the parietal lobe.

The **middle temporal gyrus**, between the upper and middle temporal sulci, is connected with the subjacent convolution by the bridges which interrupt the second temporal furrow. Above and behind it is continuous with the angular and postparietal convolutions.

The **inferior temporal gyrus** occupies the rounded infero-lateral margin of the hemisphere, and appears on both the lateral and the inferior surface of the lobe, being continuous with the occipital lobe behind (Fig. 988). Its upper boundary, formed by the middle temporal sulcus, is indistinct; its lower and mesial limit is defined by the inferior temporal sulcus, which separates it from the occipito-temporal gyrus.

The *inferior surface of the temporal lobe* is rounded in front, where it rests in the anterior cerebral fossa, but behind is modelled by the upper surface of the tentorium cerebelli and is, therefore, concave from before backward and slightly convex from side to side. It presents one fissure, the inferior temporal, and one convolution, the anterior part of the occipito-temporal.

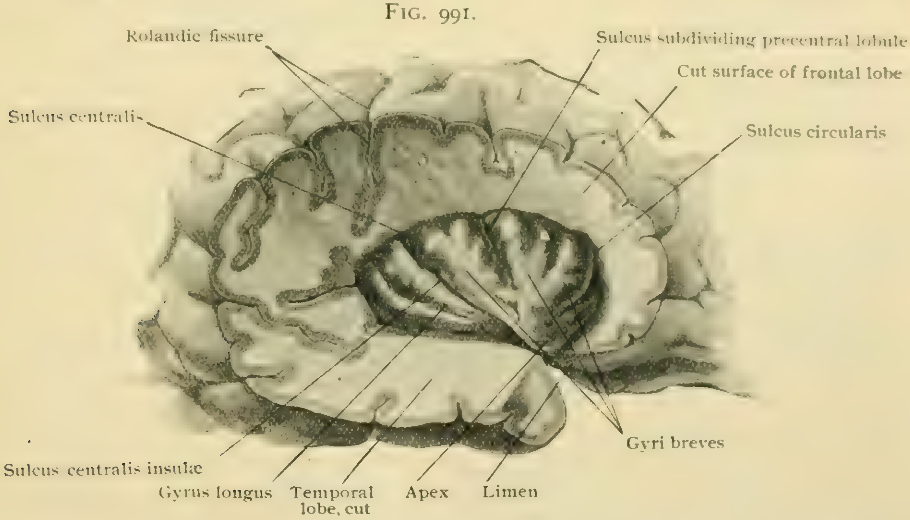
The **inferior temporal sulcus**, also called the *occipito-temporal*, courses longitudinally a short distance internal to the infero-lateral border of the hemisphere and

separates the inferior temporal from the occipito-temporal gyrus. Although for the greater part of its extent on the temporal lobe, it is not confined to this, but continues backward into the occipital lobe which, therefore, claims it as one of its furrows. The sulcus is rarely continuous, usually being broken by annectant gyri into a posterior, a middle and an anterior segment.

The **occipito-temporal gyrus** (**gyrus fusiformis**) is, as its names imply, a fusiform tract belonging partly to the occipital and partly to the temporal lobe (Fig. 989). Its two ends, in front and behind, are pointed and connected by a broader intervening tract, which is commonly broken up by secondary furrows. The temporal division of the gyrus, including approximately its anterior two-thirds, is embraced between the converging collateral fissure mesially and the inferior temporal sulcus laterally; its conventional posterior limit is the line drawn from the preoccipital notch to the isthmus of the limbic lobe, immediately beneath the hind-end of the corpus callosum.

The *superior surface of the temporal lobe* is directed towards the insula and is therefore an opercular aspect. On separating the walls of the Sylvian fissure to expose it, this buried surface of the temporal lobe often exhibits several shallow transverse furrows and indistinct gyri, the deep aspect of the temporal pole being similarly indented.

FIG. 991.



Island of Reil exposed after cutting away surrounding parts of right cerebral hemisphere.

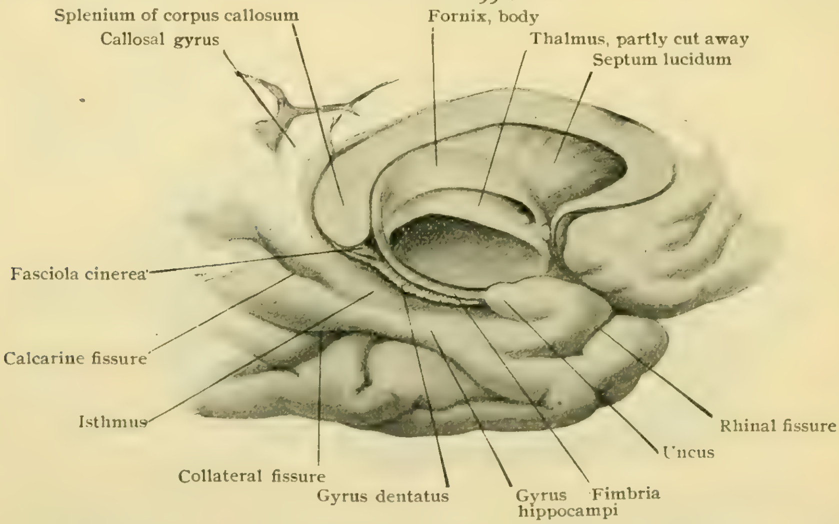
The Insula.—The insula, or *island of Reil*, sometimes also called the *central lobe*, is, in the human brain, entirely concealed within the Sylvian fissure by the approximation of the overhanging opercula. The manner in which the latter are developed from the wall surrounding the early Sylvian fossa has been described (page 1137); it remains here to note the chief features of this region in the adult brain. On examining the relations of the insula, as seen in frontal sections of the brain (Fig. 967), it will be noted (*a*) that the shell of cortical gray matter covering the sunken convolutions is directly continuous along the Sylvian fissure with that covering the convolutions on the freely exposed parts of the hemisphere; (*b*) that the insular cortex lies close to the underlying mass of gray matter, the lenticular division of the corpus striatum, a narrow tract of white matter, the external capsule, alone intervening. Since the corpus striatum is one of the earliest of the fundamental parts of the telencephalon to be developed, it is probable that its close primary relation to the surface of the hemisphere is largely responsible for the failure of the overlying cortex to keep pace with the general expansion of the adjoining parts.

When exposed, by separation or removal of the surrounding opercula (Fig. 991), the insula appears as a triangular convex field composed of a group of radiating convolutions, whose broader ends lie above and pointed ones below. The

dependent apex of the insula lies close to the anterior perforated space, with the gray matter of which the cortical sheet of the island is continuous by way of a transitional area, known as the *limen insulæ*, where the limiting sulcus of the island is incomplete. In addition to being imperfectly separated from the surrounding opercula by the curved limiting sulcus (*sulcus circularis insulæ*), the island is divided into an anterior and a posterior part by the *sulcus centralis insulæ*. This furrow continues in a general way the downward and forward direction of the fissure of Rolando, the deeper part of which is seen above the island (Fig. 991). The anterior part, or *precentral lobule*, is subdivided by two, sometimes by three, shallow grooves into three or four short downwardly converging ridges, the *gyri breves*, of which the front one is connected with the deeper part of the inferior frontal convolution by a small arched annectant *gyrus transversus*. The hind-part of the island, the *postcentral lobule*, includes a longer wedge-shaped tract, the *gyrus longus*, which below is continuous with the limbic lobe. The gyrus longus is frequently subdivided by one or more shallow furrows into secondary ridges.

The Limbic Lobe.—The limbic lobe (**gyrus fornicatus**) appears on the mesial and inferior surfaces of the hemisphere (Fig. 987) as an elongated ∩-shaped tract,

FIG. 992.



Portion of infero-mesial surface of left hemisphere, showing lower part of limbic lobe and adjacent structures.

whose ends lie closely approximated with each other and with the anterior perforated space. These extremities are further intimately associated with the two limbs of the olfactory tract, in this manner the limbic and olfactory lobes becoming, at least topographically, continuous. The limbic lobe comprises two parts, an antero-superior and an inferior, of which the former, the *callosal gyrus*, lies concentric with the upper surface of the corpus callosum, and the inferior part, the *hippocampal gyrus*, forms the mesial tract of the tentorial surface of the hemisphere. The limbic lobe is separated from the adjacent convolutions by the calloso-marginal sulcus in front and above, by the postlimbic sulcus behind, and by the anterior part of the collateral fissure below. Its demarcation from the anterior part of the temporal lobe is effected by the inconspicuous rhinal sulcus (**fissura rhinica**), or incisura temporalis, which feeble furrow in man represents the important and fundamental ectorhinal fissure of the lower animals.

The **callosal gyrus** (**gyrus cinguli**), also called the *gyrus fornicatus* (not to be mistaken, however, with the same name as applied to the entire limbic lobe), begins at the anterior perforated space, below the recurved rostrum of the corpus callosum. Thence it winds around the genu of the latter and follows the convex dorsal surface of the corpus callosum, separated however from it by the narrow *callosal sulcus* (**sulcus corporis callosi**). On reaching a point just below the splenium, around which

it bends, the callosal gyrus is markedly reduced in width by the encroachment of the calcarine fissure, the narrowed tapering tract thus formed being the upper part of the **isthmus** (**isthmus gyri fornicati**), which below joins the similarly reduced upper end of the hippocampal convolution and so establishes the continuity between the two parts of the lobe.

The **hippocampal gyrus** (**gyrus hippocampi**) curves forward from the isthmus along the mesial border of the tentorial surface of the hemisphere towards the apex of the temporal lobe, which, however, it fails to reach (Fig. 992). Its anterior extremity is distinctly thickened and forms a rounded hook-like projection, the **uncus**, which is recurved and directed backward and inward. The uncus is separated from the apex of the temporal lobe by the incisura temporalis (**fissura rhinica**), whilst the hippocampal convolution is marked off laterally by the anterior part of the collateral fissure. Although blended with the gyrus hippocampi and seemingly a part of the limbic lobe, the uncus, strictly considered, belongs to the rhinencephalon and not to the limbic lobe (Turner, Elliot Smith). The posterior end of the hippocampal convolution is incised by the anterior extremity of the calcarine fissure and so divided into two parts; of these the upper aids in forming the isthmus and is continuous with the callosal gyrus, whilst the lower one blends with the front part of the gyrus lingualis of the occipital lobe.

The Rhinencephalon.—Although a division of fundamental importance and differentiated at a very early period in the development of the human telencephalon, in the brain of man it is represented by structures, which to a great extent are rudimentary and feeble expressions of the bulky corresponding parts in the brains of many of the lower animals. Its small size in man, as compared with the voluminous structures seen in some mammals in which the rhinencephalon constitutes a large part of the entire hemisphere, is no doubt associated with the relatively feeble olfactory sense possessed by man. It is probable, however, that other and unknown factors are responsible for the development of this part of the hemisphere to a degree disproportionate to the olfactory capacity of the animal, as strikingly observed among the lower vertebrates. The conclusions deduced from comparative studies emphasize the fundamental character of the rhinencephalon as phylogenetically being the oldest part of the hemisphere. Indeed of such primary morphological significance is the rhinencephalon that it is termed the *archipallium*, as distinguished from the *neopallium*, which comprises almost the entire remainder of the hemisphere with the exception of its nucleus, the corpus striatum.

As seen in the human brain, the rhinencephalon includes the rudimentary **olfactory lobe**—represented by the olfactory bulb, the olfactory tract with its roots, the olfactory trigone, and the parolfactory area—and the **uncus** and a number of **accessory parts,** including the anterior perforated space, the gyrus subcallosus, the septum lucidum, the fornix, the hippocampus and the gyrus dentatus. Some of these accessory structures can be understood only after their relations to other parts of the brain have been considered. Deferring the details of certain of these structures, as the septum lucidum, the fornix, and the hippocampus major, until the lateral ventricles are described (page 1160), it will suffice for the present to point out their general features as related to the rhinencephalon.

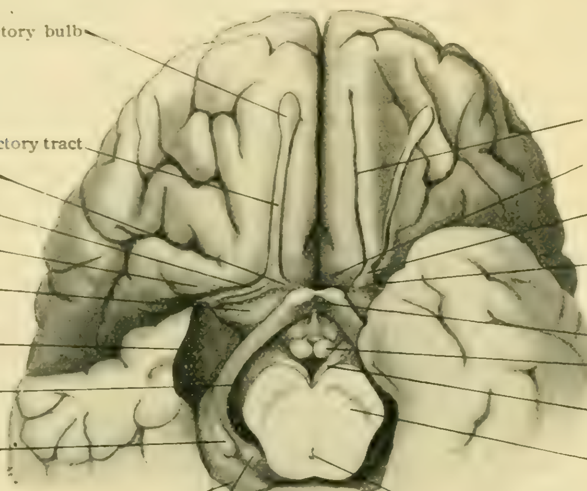
The Olfactory Lobe.—This division of the adult human brain is small and rudimentary and comprises the olfactory bulb, the olfactory tract, the olfactory trigone and the parolfactory area (Fig. 993). Of these all but the last lie on the inferior surface of the brain, whilst the parolfactory area occupies a small space on the mesial aspect of the hemisphere.

The **olfactory bulb** (**bulbus olfactorius**) is an elongated irregularly oval swelling, about 10 mm. long, from 3–4 mm. wide and about 2.5 mm. thick, which behind is continuous with the olfactory tract and below receives the olfactory filaments. Its upper surface underlies the olfactory sulcus of the orbital aspect of the frontal lobe, and its under one rests upon the cribriform plate of the ethmoid bone, through the apertures of which the bundles of the olfactory nerve-fibres ascend from the nasal mucous membrane to the bulb.

The **structure** of the olfactory bulb shares the general rudimentary condition which characterizes the lobe in man, the bulb having lost the central cavity (*ventriculus bulbi olfactorii*),

which in many animals is continuous with the fore-part of the lateral ventricle, as well as some of the six layers that may be typically represented, as in the dog's bulb. The ventral aspect of the bulb, receiving the olfactory nerves, retains most completely its nervous character and presents three chief strata (Fig. 995). (1) The *stratum of olfactory fibres* appears as a narrow zone made up of the irregularly intermingled bundles of axones of the olfactory cells situated within the olfactory area of the nasal mucous membrane. This layer is succeeded by a broader tract, (2) the *stratum of the mitral cells*, so named on account of the numerous nerve-cells of peculiar bishop's-hat form which occupy its upper border. Along its lower margin extends a narrow zone of large spherical masses, the *olfactory glomeruli*. These bodies, from .065–.090 mm. in diameter, consist of an intricate complex formed by the intertwining of the richly branching axones ascending from the olfactory cells and of the dendrites descending from the mitral cells. The interval between the upper and lower margins of the second stratum is occupied by the *molecular layer*, composed of small nerve-cells whose dendrites also enter the glomeruli. (3) The *stratum of central fibres* includes the centrally directed axones of the mitral and other nerve-cells which constitute the second link in the complicated paths by which the olfactory stimuli are carried to the cortical areas. The outer zone of this stratum is known

FIG. 993.



Anterior part of inferior surface of brain, showing parts of olfactory lobe and structures within interpeduncular space; tip of right temporal lobe has been removed.

as the *granular layer* and consists of many small nerve-cells intermingled with the fibres. The deeper part of the stratum of nerve-fibres encloses some larger nerve-cells of stellate or elongated form. The central part of the bulb, which represents the obliterated ventricular space, is filled by a gelatinous substance resembling modified neuroglia.

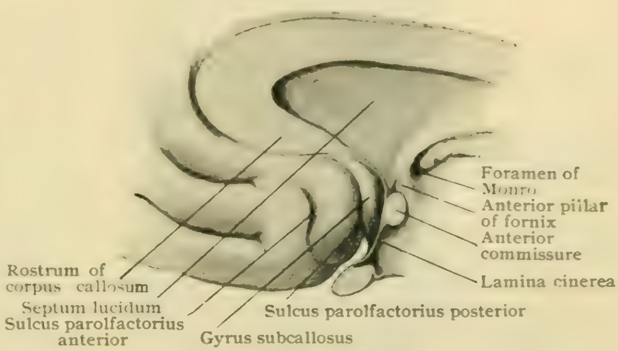
The **olfactory tract** (tractus olfactorius) is a narrow band of light color, which extends from the olfactory bulb in front to the olfactory trigone behind (Fig. 993). It measures about 2 cm. in length and 2.5 mm. in width, but is broader at its posterior extremity, from which the *olfactory striæ*, as its roots are called, diverge. Its ventral surface is flat and its narrow dorsal one ridged, the tract appearing in transverse section more or less triangular in outline.

The **structure** of the olfactory tract further emphasizes the rudimentary condition of the part in man. The ventral aspect and the rounded adjoining borders consist of: (1) a *stratum of nerve-fibres*, longitudinally coursing and therefore transversely cut in cross-sections, which covers the sides and dorsal surface of the tract and is reduced to an extremely thin and rudimentary sheet. Next follows (2) a *gelatinous stratum*, which represents the obliterated ventricular cavity seen in many lower animals. Succeeding this and forming the thickest layer of the tract lies (3) the dorsal *stratum of gray matter*, which still retains its importance as a tract of cortical gray substance from which fibres pass to other parts of the hemisphere (page 1222).

The **olfactory striæ,** the so-called *roots of the olfactory tract* (Fig. 993), are usually two, the mesial and the lateral, an additional intermediate root being sometimes represented by faint strands. The *mesial stria* bends sharply inward, passes along the inner margin of the olfactory trigone and disappears on the mesial surface of the hemisphere by joining probably partly the callosal and partly the subcallosal gyri (Fig. 994). The diverging *lateral stria* obliquely courses along the antero-lateral margin of the perforated space, but usually disappears as a distinct tract before it can be traced to the uncus, its probable destination (page 1222). Occasionally the lateral root is represented by two strands, an outer and an inner, the last one fading away in the substance of the anterior perforated space. An additional *intermediate stria* is sometimes recognizable for a short time before it too sinks into the anterior perforated space.

The **olfactory trigone** (**trigonum olfactorium**) is the three-sided slightly convex area embraced by the two roots of the olfactory tract at the sides, and behind separated from the anterior perforated space by a groove (**sulcus parolfactorius posterior**). The triangular area seen on the inferior surface of the hemisphere (Fig. 993) is really the under aspect of a more extensive pyramidal elevation, the **tuberculum olfactorium,** which, however, lies in large part within the olfactory sulcus and is therefore superficially not visible except at its base, the trigone. Retzius regards this part of the hemisphere as a constant deep convolution, *gyrus tuberis olfactorius*, from which proceed two ridges, *gyrus olfactorius medialis* and *lateralis*. These bend respectively inward and outward and support the white strands of nerve-fibres, the striæ olfactorii, which are usually described as the roots of the olfactory tract. The tuberculum olfactorium contains a considerable amount of gray matter, which is a part of the peripheral olfactory cortex and, with other portions of this sheet, shares in the reception of axones from the mitral cells and in the origin of fibres passing to other parts of the rhinencephalon.

FIG. 994.



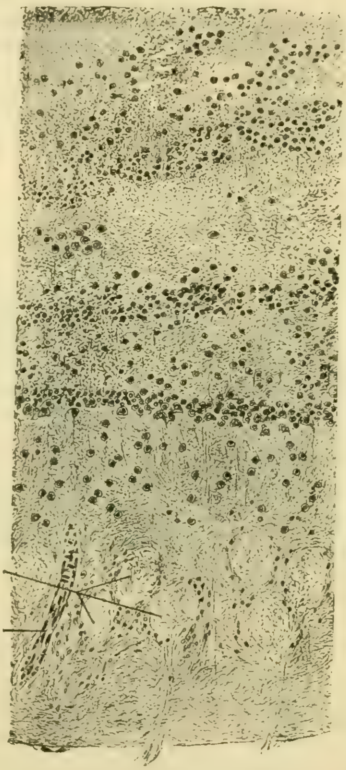
Portion of mesial surface of right hemisphere, showing gyrus subcallosus and parolfactory area.

The **parolfactory area,** or *field of Broca*, lies as a small curved tract upon the mesial surface of the hemisphere, just in front of and below the *gyrus subcallosus* which extends from the rostrum to the corpus callosum (Fig. 994). The area parolfactoria is bounded in front by the *sulcus parolfactorius anterior* and behind by the *sulcus parolfactorius posterior*, and is connected in front with the superior frontal gyrus, above with the callosal gyrus and below with the inner part of the trigonum olfactorium, the mesial olfactory gyrus above mentioned.

The **anterior perforated space** (**substantia perforata anterior**) is an irregularly triangular area (Fig. 993) lying behind the trigonum olfactorium, from which it is separated by the obliquely coursing sulcus parolfactorius posterior, and in front of the optic commissure. Its inner part is narrow and extends as a point between the mesial root of the olfactory tract and the lower end of the subcallosal gyrus. Its broader outer part extends into the floor of the stem of the Sylvian fissure and behind reaches the deeper part of the uncus and, more medially, the optic tract. Its designation as perforated is justified by the large number of small oval apertures for the transmission of perforating branches from the antero-mesial and antero-lateral groups of the basal arteries. These openings, most numerous along the front margin of the space, are disposed with some regularity in parallel rows and

decrease in size as they approach the inner border (Foville). The substance of the space proper consists of a thin sheet of gray matter containing groups of nerve-cells, some of which constitute the nuclei of primary centres interposed in the paths connecting the olfactory lobe with the secondary (cortical) olfactory centres (page 1222). In addition to the white strands of nerve-fibres composing the olfactory striæ which after a longer or shorter superficial course sink into the substance of the perforated space, an obliquely directed narrow ribbon-like tract, the *diagonal band of Broca*, may be sometimes made out along the inner margin of the area perforata. In front it is continuous with the subcallosal gyrus and behind passes along the optic tract towards the anterior end of the hippocampal convolution. The band is of interest as being probably the beginning, on the basal surface of the brain, of at least a part of the fibre-tracts contained within the rudimentary supracallosal gyrus (page 1157) that, in turn, is prolonged into the gyrus dentatus.

Fig. 995.



Transverse section of olfactory bulb; drawing includes part of bulb lying ventral to atrophic ventricular area. × 90.

The **uncus** is the thickened anterior extremity of the gyrus hippocampi, recurved around the front end of the hippocampal fissure (Fig. 992). Antero-inferiorly it is separated from the adjacent part of the temporal lobe by the inconspicuous incisura temporalis or rhinal sulcus, which in animals possessing a well developed rhinencephalon constitutes a definite boundary between this part of the hemisphere and the pallium. With its deeper surface the uncus is in close relation with the anterior perforated space, whilst postero-mesially it is connected with the fimbria (page 1165) and the gyrus dentatus (page 1166). Although seemingly a part of the limbic lobe, the comparative studies of Turner and of Elliot Smith have established its morphological independence from the last-named lobe and emphasized its relation with the rhinencephalon. With the lateral olfactory stria, the uncus constitutes in man the feeble representation of the large and conspicuous pyramidal lobe, which in many animals forms the most massive part of the olfactory brain.

The **accessory parts** of the rhinencephalon include structures which, for the most part, constitute collectively an elaborate path by which the olfactory cortical centres are connected with each other, on the one hand, and with the optic thalamus and lower levels on the other. Since these structures are by position closely associated with parts of the brain still to be described, with the exception of the anterior perforated space already noted (page 1153), they will be merely mentioned here, as components of the rhinencephalon, their details being deferred until the related parts are considered.

The **fornix** (page 1158), the **fimbria** (page 1165) and the **hippocampus** (page 1165), all seen within the lateral ventricle (page 1164), constitute important paths by which fibres pass to and from the olfactory cortical centre. The **gyrus subcallosus** (page 1153), the **gyrus supracallosus** (page 1157) and the **gyrus dentatus** (page 1166) together form an additional arched tract, which, beginning at the base of the brain, follows closely the convex surface of the corpus callosum as far

as its hind-end and then, as the dentate gyrus, extends forward along the inner surface of the hippocampus to the uncus. The **septum lucidum** (page 1159), a sickle-shaped partition which lies between the lateral ventricles, the corpus callosum and the fornix, is also a constituent of the olfactory path, as are also, probably, the **tænia semicircularis** (page 1162) and the **nucleus amygdalæ** (page 1172).

In the foregoing description of the rhinencephalon only such parts have been included as seem warranted on morphological grounds (Turner, Elliot Smith and Cunningham). It should be pointed out, however, that the German and French anatomists include also the limbic lobe, the division and constitution of the rhinencephalon accordingly being as follows:

RHINENCEPHALON.

I. Peripheral Portion

OLFACTORY LOBE

A. Anterior part:

1. Bulbus olfactorius
2. Tractus olfactorius
3. Tuberculum olfactorium
4. Area parolfactoria

B. Posterior part:

5. Substantia perforata anterior
6. Gyrus subcallosus

II. Central Portion

CORTEX

1. Gyrus callosus
2. Gyrus hippocampi
3. Gyrus uncinatus
4. Hippocampus
5. Gyrus dentatus
6. Gyrus supracallosus

Architecture of the Cerebral Hemispheres.

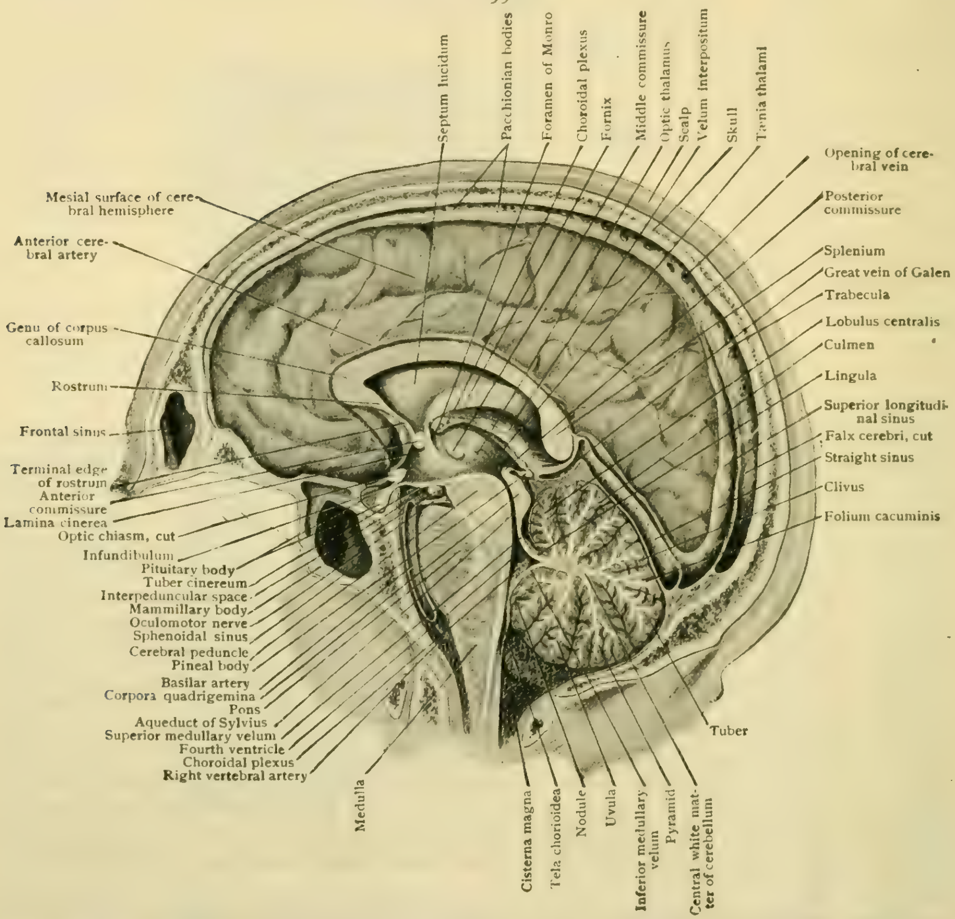
On drawing apart the walls of the great longitudinal fissure, it will be seen that, while in front and behind this cleft completely separates the hemispheres, the latter are connected in the intervening part of their length by a robust commissure, the *corpus callosum*, which floors the fissure along the middle part of its course. On making sections of the hemisphere above the level of this bridge, either in the frontal or transverse plane, the hemibrain is found to be composed of the thin reddish brown sheet of *cortical gray matter* (**substantia corticalis**), which everywhere constitutes an unbroken stratum, and the enclosed large tract of white matter, the *centrum ovale*. Beneath the corpus callosum lies the *lateral ventricle*, the cavity enclosed within the hemisphere, in whose lateral wall and floor appears the mesial division of the corpus striatum, the *caudate nucleus*, whilst further outward is lodged the lateral division of the nuclear mass of the end-brain, the *lenticular nucleus*. Attached to the under surface of the posterior half of the corpus callosum is the arched layer of fibres known as the *fornix*, and below the latter, covering to a large extent the upper surface of the thalamus which forms a part of the floor of the lateral ventricle, lies the thin highly vascular sheet, the *velum interpositum*. These and the other structures more or less closely related to the lateral ventricle claim fuller description, which may now be undertaken.

The Corpus Callosum.—This structure is the great commissure which connects the hemispheres and, in addition, affords passage to fibres that arise from the thalamus and, probably, other nuclei outside the hemisphere and proceed to the cerebral cortex. It lies considerably nearer the anterior than the posterior end of the hemisphere and occupies approximately one half of the latter's length. Seen in mesial sagittal section (Fig. 996), the corpus callosum appears as a robust arched structure, white in color and composed of nerve-fibres transversely cut, whose ends are considerably thicker than the intermediate portion, the **body** (**truncus corporis callosi**). Its upper surface is convex, partly free and partly covered by the overlying hemisphere, and its lower one is concave and, where not attached to the fornix and the septum lucidum, clothed by the ependyma lining the ventricle. Its length is about 7 cm. ($2\frac{3}{4}$ in.) and its greatest thickness, at its posterior extremity, is about 8 mm. It is widest behind, where it measures about 20 mm., and somewhat narrower in front. The thickened front end, the **genu,** bends backward and is

prolonged into the sharply recurved and tapering **rostrum,** whose thin edge is continued backward and downward into the lamina cinerea, the attenuated anterior wall of the third ventricle (page 1132). The rounded and massive posterior end of the corpus callosum, known as the **splenium,** overlies the pineal body and the superior colliculi, and above bounds the cleft through which the pia mater gains the velum interpositum (page 1162).

The convex **upper surface** of the corpus callosum, where it forms the bottom of the longitudinal fissure, is free, except behind where in contact with the posterior part of the falx cerebri ; laterally it is partially overlaid by the callosal gyrus, which,

FIG. 996.



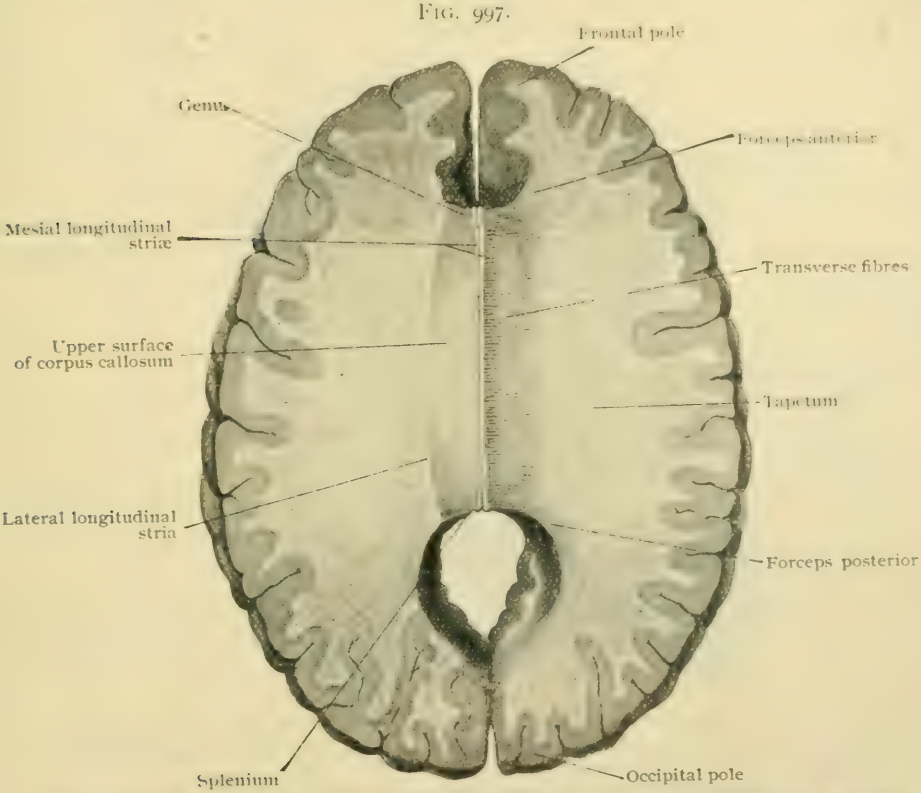
Mesial section of brain *in situ*, showing relations to skull and dura ; cerebral falx has been partly removed, but arachnoid and pia are still in place.

however, is separated from it by the intervening *callosal sulcus* (sulcus corporis callosi). Although consisting practically exclusively of transversely coursing nerve-fibres, which produce a corresponding cross striation, the upper surface of the corpus callosum (Fig. 997) is covered by a thin atrophic layer of gray matter (**induseum griseum**) which laterally is continuous with the cortical substance of the callosal gyrus and contains rudimentary strands of longitudinal nerve-fibres. These are arranged on each side of the slight groove marking the mid-line in two strands ; the one, the **stria medialis,** is placed close to the strand of the opposite side and with it constitutes the so-called *nerves of Lancisi.* The other strand, the **stria lateralis,** or *tænia tecta*, lies farther outward and is covered by the overhanging callosal gyrus. These rudimentary structures, including the thin sheet of gray matter and the two

striæ, represent an atrophic convolution, the *gyrus supracallosus*. Traced forward and around the recurved genu and rostrum, the mesial stria is prolonged into the *gyrus subcallosus*, a small crescentic cortical tract on the mesial surface of the hemisphere immediately below the rostrum (Fig. 994); while the lateral stria is continued into the area parolfactoria (page 1153) and into the anterior perforated space. When followed backward and around the splenium, the striæ and gray matter of the corpus callosum become continuous with the gyrus dentatus and, by way of the latter, with the uncus.

The **under surface** of the corpus callosum (Fig. 998) exhibits a very evident transverse striation and forms the roof of the anterior cornu and body of both lateral ventricles. With the exception of a strip of varying width along the mesial plane, where attached to the septum lucidum in front and to the triangular

Fig. 997.



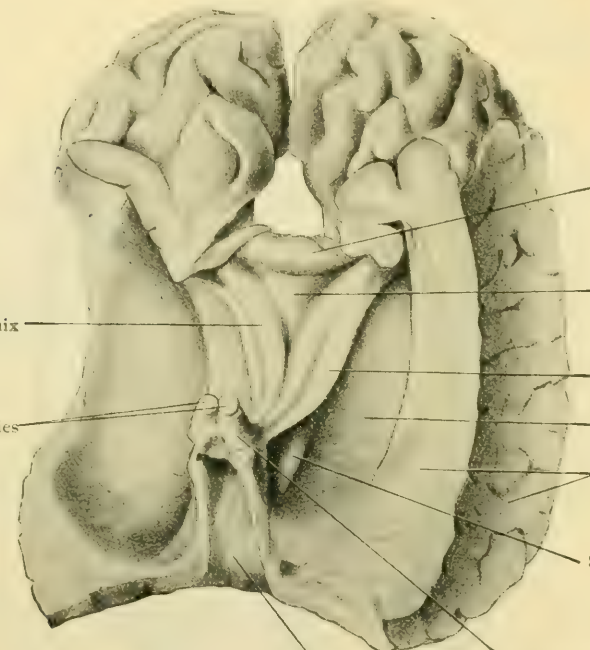
Cerebral hemispheres from which upper and median parts have been removed to expose corpus callosum; on left side longitudinal striæ and thin layer of gray matter cover upper surface of corpus callosum; on right side these have been scraped away to expose transverse fibres and anterior and posterior forceps.

body of the fornix behind, the corpus callosum is free and covered with the ependyma which lines the ventricular spaces. In consequence of the bridge being shorter than the length of the hemispheres, from most parts of which it receives fibres, the latter are consolidated at the ends of the corpus callosum and give rise to the genu and the splenium. On gaining the lateral margins of the corpus callosum, its fibres are no longer restrained but radiate in all directions (**radiatio corporis callosi**) towards the cortex and intersect the fibres of the corona radiata (page 1186). Those traversing the thinner body and upper part of the splenium of the commissure pass laterally and in each hemisphere from a thin but definite fibre-sheet, known as the **tapetum**, which extends over the lateral ventricle, especially its posterior horn, and constitutes the lateral wall of its posterior cornu and of the adjacent part of the descending horn. The fibres composing the fore-part of the genu turn forward as a distinct band, the **forceps anterior**, towards the frontal

pole of the hemisphere, whilst those constituting the greater part of the splenium are consolidated into a robust strand, the **forceps posterior,** which sweeps abruptly backward into the occipital lobe and in its course produces a curved ridge on the fore-part of the inner wall of the posterior horn of the lateral ventricle.

The Fornix.—The fornix is an arched structure, white in color, and composed, for the most part, of two crescentic tracts of longitudinally coursing nerve-fibres. The two ends of these narrow crescents are free for some distance, but along their medial borders the intervening parts are connected with the under surface of the corpus callosum and with each other (Fig. 998), thus producing a triangular field, the **body** (**corpus fornicis**), whose apex is directed forward and is prolonged into two slender diverging stalks, the *anterior pillars*, and whose lateral angles are continued into the downwardly arching *posterior pillars*. The upper surface of the body is subdivided into an attached and an unattached area. The former is a small

FIG. 998.



Dissection of brain, showing under surface of fornix and corpus callosum.

narrow triangle, the posterior and broader part of which corresponds with the attachment of the fornix to the under surface of the corpus callosum; whilst the anterior part is a mere mesial strip denoting the line along which the arching fornix is blended with the septum lucidum, the sickle-shaped partition that fills the interval between the corpus callosum and the fornix and separates the anterior horns of the lateral ventricles. On either side of the attached field, the fornix presents a smooth and somewhat thicker marginal zone, which forms part of the floor of the lateral ventricle and, depending upon the size and distention of the ventricular space, either extends laterally as a horizontally directed wing that overlies a part of the thalamus, or descends obliquely towards the thalamus upon whose upper surface the margin of the fornix indirectly rests. The triangular central sheet of the fornix, bounded by its unattached margins laterally and the splenium behind, exhibits transverse striation due to the presence of bundles of commissural fibres connecting the hippocampi of the two sides. This part of the fornix constitutes the **commissura hippocampi,** also known as the *psalterium* or *lyra*. A narrow horizontal cleft, the so-called *ventricle of Verga* (**cavum**

psalterii), sometimes intervenes as the result of imperfect union, between the under surface of the corpus callosum and the middle part of the body of the fornix. It should be understood, however, that this cleft is not a part of the series of true ventricular spaces. The under surface of the fornix rests upon the velum interpositum, which thus separates it from the third ventricle and the upper surfaces of the two thalami which it overlies.

The **anterior pillars of the fornix** (**columnae fornicis**) are two slender cylindrical strands, which, slightly diverging as they leave the anterior angle of the body, arch downward and forward, then somewhat backward, and descend to the basal surface of the brain, where they end in the mammillary bodies. In their descent they lie in the extreme front part of the lateral walls of the third ventricle, where they show as ridges (Fig. 976), and form on each side, the upper and anterior boundary of the foramen of Monro. A short distance below the latter opening, the pillar disappears from the ventricular wall in consequence of the increasing divergence from the mesial plane. On reaching the mammillary body on the basal surface of the brain, the fibres composing the anterior pillar are interrupted to a large extent in the mammillary nuclei (Fig. 967). The connections of these stations are described elsewhere (page 1129), suffice it here to recall that while a part of their fibres are continued to lower levels, a very considerable strand, known as the *bundle of Vicq d'Azyr*, arches upward and completes the connection between the fornix and the thalamus, in the anterior part of which these mammillo-thalamic fibres end. The relations of the anterior pillars to the olfactory paths are noted in connection with the olfactory nerve (page 1222).

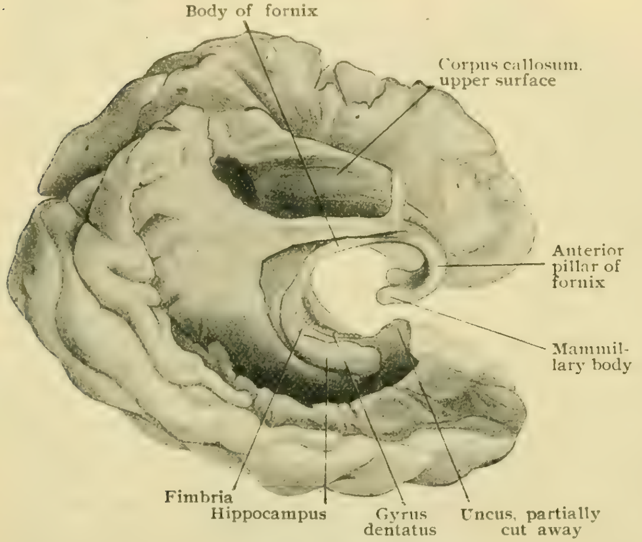
The **posterior pillars of the fornix** (**crura fornicis**), the widely diverging backward prolongations from the lateral angles of its body, are at first attached to the under surface of the corpus callosum. They then turn outward, and, sweeping around the posterior ends of the optic thalami, enter the descending horns of the lateral ventricles and arch downward along the dorso-mesial border of the conspicuous *hippocampi*, the elevations which mark the inferior horns of the lateral ventricles. On reaching this situation, however, the posterior pillar no longer retains its previous form, but now appears much reduced in size, as a white flattened band, known as the **fimbria**, which, broadest in the middle of its course, narrows as it descends, and ends by joining the uncus at the lower extremity of the ventricle. The progressive diminution of the fimbria during its descent is due to the contribution of many of its fibres to the sheet of white matter, the *alveus*, which covers the hippocampus. It is evident that the fornix constitutes, by means of its several parts, a continuous tract of longitudinally coursing fibres, which convey impulses from the chief cortical olfactory centre, the uncus and the hippocampus, to the mammillary nuclei and thence, in great part, by the bundle of Vicq d'Azyr to the thalamus.

The fornix may be considered, in a sense, as a tract of white matter representing the lower edge of the hemisphere; in front and behind these edges remain ununited and more or less widely apart. Beneath the corpus callosum they become attached not only to the under surface of this bridge, but also to each other by the commissural fibres of the psalterium. The peculiar course of the fornix is referable to the backward and downward expansion of the developing hemispheres, as the result of which the posterior end of the fornix follows the hippocampus in its migration into the descending horn of the lateral ventricle as the temporal lobe is developed. Further consideration of these changes, however, may be deferred (page 1167) until the associated structures have been described in connection with the lateral ventricle.

The Septum Lucidum.—The septum lucidum (**septum pellucidum**) is the thin median vertical partition which fills the interval between the corpus callosum above and in front and the fornix behind (Fig. 996), with which structures its margins are firmly attached. It separates the anterior horns and adjoining parts of the lateral ventricles and is, in a modified form, triangular in shape when viewed laterally. The sides of the triangle are all curved and its anterior angle, received within the bend of the genu, is blunt and rounded. Its posterior angle is narrow and extends for a variable distance between the under surface of the body of the corpus callosum and the upper arched surface of the body of the fornix. The lower angle occupies the interval between the thin edge of the rostrum and the anterior pillars

of the fornix. The septum consists of two thin layers (**laminae septi pellucidi**), between which lies a narrow cleft (**cavum septi pellucidi**) to which the misleading name, *fifth ventricle*, has long been applied. This space, very variable in extent and width, is usually so narrow and contains such a small quantity of modified lymph, that the laminæ forming its walls are in apposition. It is entirely closed and, therefore, cut off from the true ventricular system ; neither is it lined with ependyma. The septum lucidum in man is the rudimentary representation of what in many of the lower (macrosmatic) animals is a much more important tract of cortical substance. In some animals, as for example, the rabbit, cat and dog, the septum is solid, a cleft never appearing within it. Notwithstanding the reduction which it has suffered in man, the septum exhibits in its structure its relation to the cortex, comprising, from its cleft outward : (1) a thin layer of nerve-fibres, (2) an uncertain layer of gray matter containing numerous nerve-cells of pyramidal form, and, next to the lateral ventricle, (3) a layer of nerve-fibres, the ventricular surface of which is clothed with the usual ependyma. It is probable that axones proceeding from the cells within the septum lucidum are constituents of the olfactory strands within the fornix, which pass to the hippocampus and the uncus, and of the tænia semicircularis (page 1162), terminating in the amygdaloid nucleus (page 1172).

FIG. 999.



Dissection showing fornix in front and above; drawn from preparation and Steger model.

The Lateral Ventricles.—The lateral ventricles (**ventricula laterales**) are a pair of irregular cavities contained within the cerebral hemispheres. They are developed as outpouchings from the original cavity of the end-brain and for a time communicate with this space by wide openings. The latter, however, fail to keep pace in their growth with the expansion of the hemispheres, and in the fully developed brain are represented by the small apertures of the *foramen of Monro*, which maintains communication between the lateral and third ventricles, the last-named space representing the primary cavity of the fore-brain.

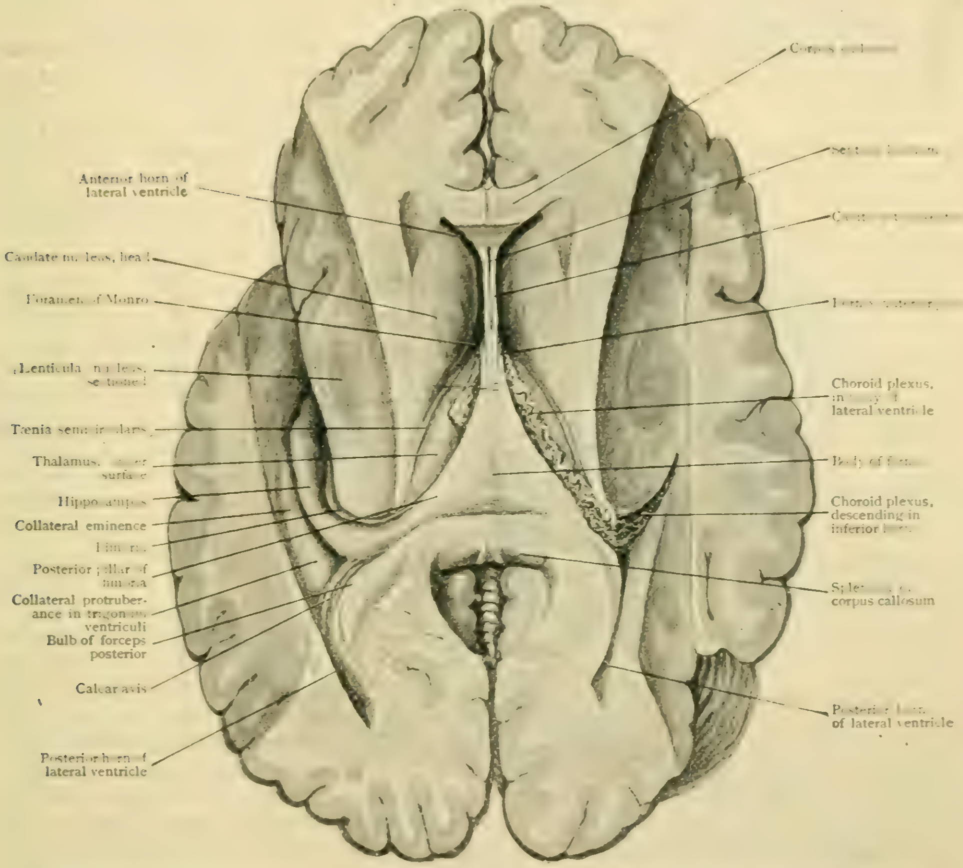
When viewed from above, after removal of its roof, the corpus callosum and its lateral extensions, each lateral ventricle appears as an elongated, irregularly curved cavity (Fig. 1000), which extends for about two-thirds of the entire length of the hemisphere and, in addition, penetrates the temporal lobe almost to its pole. It is lined, as are all the other true ventricles, with a delicate epithelial layer, the *ependyma*, which likewise clothes the structures which encroach upon its lumen, as the caudate nucleus and the thalamus, as well as those which seemingly hang free within it, as the choroid plexus and the fornix. It is usual to describe the ventricle as consisting of four parts, the *body*, and the *anterior*, *posterior* and *inferior horns*. The anterior horn and the body are practically one and separated by only an arbitrary division ; the posterior and the inferior horn extend into the occipital and the temporal lobe respectively, whilst the anterior horn enters the frontal lobe.

The **anterior horn** (**cornu anterius**) includes from the tip of the ventricle to the foramen of Monro, the latter corresponding with the anterior limit of the conspicuous choroid plexus, curves forward and outward around the head of the caudate nucleus into the white substance of the frontal lobe and in frontal sections (Fig.

1007) appears triangular in outline. The upper side or base of the triangle, slightly curved towards the ventricle, is the lower surface of the arched corpus callosum and its antero-lateral radiations; the mesial side is approximately vertical and formed by the septum lucidum; the lateral side bulges strongly towards the ventricle in correspondence with the convexity of the massive head of the caudate nucleus. The floor of this part of the ventricle is narrow, often a mere groove along the junction of the sloping lateral and vertical mesial wall, and in front passes insensibly into the concave anterior wall, formed by the lateral part of the hind surface of the genu of **the corpus callosum.**

The **body** (**pars centralis**) of the lateral ventricle includes that part of the space which extends from the foramen of Monro to the bifurcation of the ventricle into its

FIG. 1009.



Lateral ventricles seen from above after partial removal of corpus callosum and cerebral hemispheres.

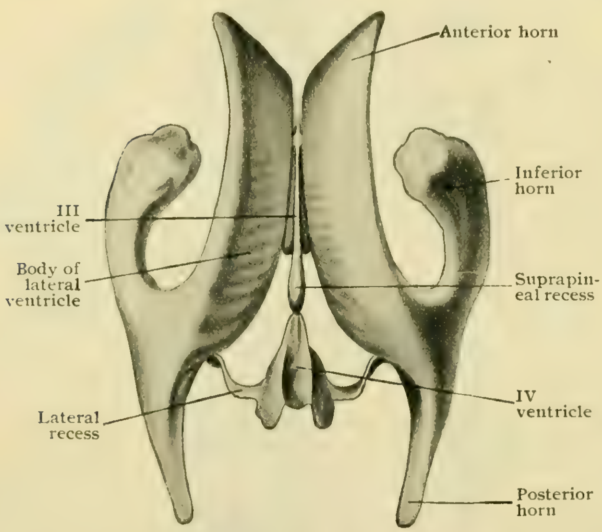
posterior and inferior horns, opposite the splenium of the corpus callosum. When viewed in frontal sections (Fig. 1010), it appears as a narrow, obliquely horizontal cleft, directed somewhat upward, roofed in by the corpus callosum. Its mesial wall is formed in front by the hind part of the septum lucidum and behind the latter by the fornix where it is attached to the under surface of the corpus callosum. A distinct lateral wall is wanting, the ventricle being here closed by the meeting of the floor and roof. Its **floor** is constituted by several structures of importance which, named from without inward, are: (1) the *caudate nucleus*; (2) an oblique *groove* (**sulcus intermedius**), which extends from before backward and outward, between the caudate nucleus and the thalamus, and lodges, in addition to the vein of the corpus striatum, a white band of nerve-fibres known as the *tænia semicircularis*; (3) a narrow portion of the upper surface of the *thalamus*, which is

almost completely masked by the overlying choroid plexus; (4) the *choroid plexus* of the lateral ventricle; and (5) the lateral edge of the *fornix*. The caudate nucleus will be subsequently described (page 1169), suffice it to note its rapid diminution in size, as it curves backward and downward on the roof of the inferior horn.

The tænia semicircularis is more or less hidden by the superficially placed *vein of the corpus striatum* (**vena terminalis**), which lies immediately beneath the ependyma and shows as a distinct sinuous ridge. Receiving tributaries from the adjacent parts of the thalamus, the caudate nucleus and the walls of the anterior horn, including the septum lucidum, the vein passes to the foramen of Monro, where, meeting with the choroid vein at the apex of the velum interpositum, it forms with the last-named vessel the vein of Galen.

The **tænia semicircularis,** or *stria terminalis*, the band-like tract of nerve-fibres occupying the sulcus intermedius, is a part of the complex pathway by which the primary and secondary olfactory centres are united. Its component fibres arise partly in the anterior perforated space and partly in the septum lucidum from which centres, reinforced by fibres from the anterior commissure, they converge towards the sulcus intermedius which, they then follow. After leaving the body of the lateral ventricle they descend within the roof of the inferior horn, in close relation to the recurved tail of the caudate nucleus, to end within the amygdaloid nucleus (page 1172).

Fig. 1001.

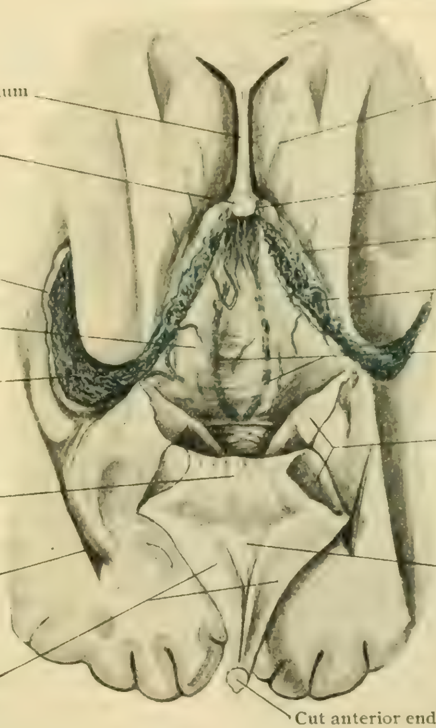


Cast of ventricles, viewed from above. × ⅔. (*Retzius*.)

The **choroid plexus** (**plexus chorioideus ventriculi lateralis**) is a convoluted vascular complex which occupies the lateral margin of the pial sheet, the velum interpositum, within the body of the lateral ventricle, and, in addition, descends along the inferior horn of the lateral ventricle to its tip. In order to understand the relations of the choroid plexus, those of the larger sheet, of which it is part, must be described. The **velum interpositum** (**tela chorioidea ventriculi tertii**) is a delicate sheet of pia mater whose upper surface is exposed after removal of the corpus callosum and the body of the fornix. When viewed from above (Fig. 1002) it is triangular in outline, its apex lying at the foramen of Monro and its lateral basal angles extending into the descending horns of the lateral ventricles. Its inferior surface forms the roof of the third ventricle, beyond which on each side it covers the greater part of the upper surface of the thalamus and, in turn, is overlaid by the fornix. Behind, the velum interpositum is continuous beneath the splenium of the corpus callosum with the pia mater investing the external surface of the hemisphere. This relation readily gives rise to the impression that the pial tissue has gained entrance to the ventricles by growing forward through the cleft beneath the splenium and the fornix. That such, however, is not the case will be pointed out later, when the development of this sheet is considered (page 1194). The relation of the velum interpositum to the ventricular cavities should be carefully noted by tracing the ependyma from the caudate nucleus inward. Leaving the convex surface of this structure, the ventricular lining covers the sulcus terminalis with its vein, and passes for a short distance over the adjoining outer part of the upper surface of the thalamus. This zone (**lamina affixa**) narrows in front and behind, and where broadest measures from 5–7 mm. Along the

inner margin of this zone the ependyma leaves the surface of the thalamus and passes onto the villous projections (Fig. 1003) of pia mater containing the convolutions of blood-vessels of which the choroid plexus is composed. Each projection, (**glomus chorioideum**) consists of: (1) a capillary complex formed by the terminal twigs of the anterior and posterior choroidal arteries, the former of which gains the interior through the choroidal fissure in the inferior horn of the lateral ventricle; (2) the connective tissue of the pia; and (3) the ependymal layer (**lamina chorioidea epithelialis**), which everywhere invests the pial plications and, therefore, excludes the vascular tissue from actual entrance into the ventricular cavity. While inconspicuous and often overlooked, this ependymal layer is of much morphological significance, since it represents all that persists in certain localities of the true wall of the hemisphere. After leaving the surface of the thalamus and investing the vascular pro-

FIG. 1002.



Dissection of brain, showing velum interpositum and choroid plexuses of lateral ventricles; seen from above after removal of corpus callosum and fornix; latter has been cut through in front and behind and turned back, exposing its under surface.

jections constituting the choroidal plexus, the ependyma becomes attached along the **tænia fornicis** to the thin lateral margin of the fornix, beneath which the velum interpositum protrudes to expand into the choroid plexus within the body of the ventricle.

The plexus is not confined to this part of the space, but follows the hippocampus to the lower end of the inferior horn. The relation of the vascular pial tissue to this extension of the ventricle is, however, the same as within the body, since the glomeruli here, as there, are completely invested by the ependyma, which they invaginate along a groove, the **choroidal fissure,** above the hippocampus, in the same manner as they do higher in the ventricle. The line of attachment of the ependyma to the wall of the horn, **tænia fimbriæ,** follows the recurved tail of the caudate nucleus, just beneath which it lies, on the one hand, and the thin mesial edge of the fimbria (the continuation of the fornix) on the other. On pulling out

the entire choroid plexus of the lateral ventricle, the ependyma is torn away and an artificial opening is produced, which may be followed, as a curved narrow cleft, from the lower end of the inferior horn upward above the hippocampus and over the dorsal surface of the thalamus, beneath the fornix and the splenium, to the exterior of the hemisphere. When traced forward from its attachment along the upper surface of the thalamus, the line of the reflection of the ependyma, **tænia chorioidea,** leads to just above the foramen of Monro (Fig. 966), where it is joined by the similar line of the opposite ventricle. From this point the choroidal line of ependymal reflection is continuous with the **tænia thalami,** the sharp ridge which marks the junction of the superior and mesial surface of the thalamus (page 1119). Leaving the surface of the latter along this ridge, the ependymal layer covers the under side of the velum interpositum, as well as the double row of vascular villous projections, which, one on each side of the mid-line of the roof, constitute the choroid plexus of the third ventricle (Fig. 974). Although similar in its general structure, this vascular fringe is much smaller and less conspicuous than that within the lateral ventricle.

It is evident from the foregoing description, that communication between the third and lateral ventricles is completely interrupted by the attachment of the ependymal layer and that at only one place, the foramen of Monro (page 1060), does such communication exist. It is of interest to note that these several lines of ependymal reflection—the tænia chorioidea, the tænia thalami and the tænia fornicis and its prolongation, the tænia fimbriæ—form a continuous line which morphologically marks the transition of the thicker nervous part of the wall of the hemisphere into the thin and atrophic area, which early undergoes an invagination leading to the production of voluminous vascular structures later seen in the definite choroid plexuses of the lateral and third ventricles. Along the margin of the choroidal fissure, at which such invagination primarily occurs, the white matter of the hemisphere becomes condensed into the tract of the fornix and its downward prolongation, the fimbria. These structures, together with the reflected ependyma and the septum lucidum, are regarded, therefore, as modified parts of the mesial surface of the hemisphere.

The **inferior horn** (cornu inferius), also called the *descending horn*, begins above at the hind-end of the body of the ventricle, thence curves backward and outward around the thalamus, and sweeps downward and forward and a little inward (Fig. 1000) into the temporal lobe well towards its tip, which, however, it fails to reach by about 2 cm. Its descent is not only very abrupt, but limited for the most part to almost a vertical plane; hence this part of the ventricle does not diverge to any considerable extent beyond the plane of the gyrus hippocampi, just to the outer side of which the lower end of the inferior horn lies. The *roof* of this cornu is formed chiefly by the tapetum of the corpus callosum, and within it descend the recurved attenuated tail of the caudate nucleus and the tænia semicircularis to join a rounded mass of gray matter, the amygdaloid nucleus (page 1172), which lies embedded within the temporal lobe, slightly above and in front of the lower end of the inferior horn (Fig. 967). The **floor** of the inferior horn begins above in the triangular area, the **trigonum ventriculi,** between the diverging inferior and posterior horns. The greater part of this field is occupied by a low convexity, the **collateral protuberance** (trigonum collaterale), which is continued into a rounded ridge, the **collateral eminence** (eminentia

FIG. 1003.

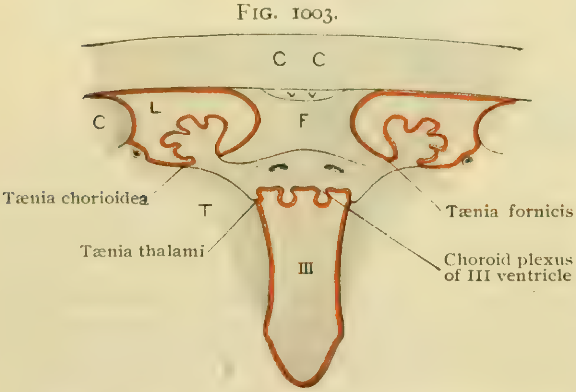
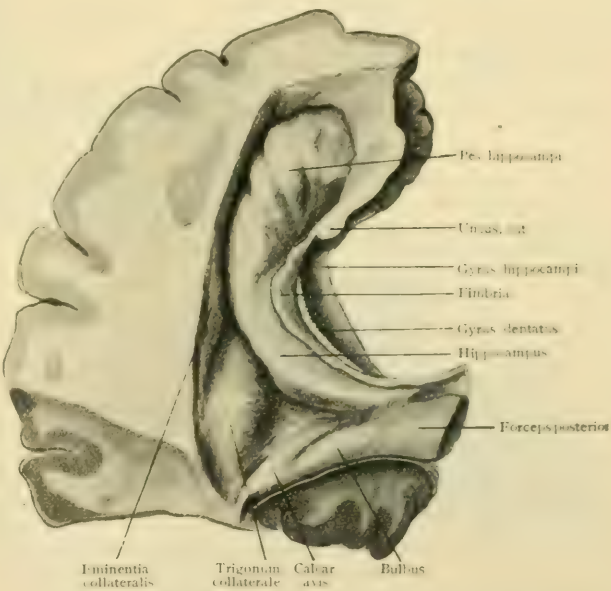


Diagram showing relation of pial tissue in velum interpositum to ependyma in lateral and third ventricle; ependyma is represented by red line; *c*, *c*, corpus callosum; *F*, fornix, *vv*, so-called ventricle of Verga; *C*, *T*, caudate nucleus and thalamus.

collateralis), that extends for a variable distance along the outer part of the floor of the inferior horn. This elevation is uncertain as to prominence and length, but even when well developed does not reach the lower extremity of the ventricle. It results from the invagination of the wall of the early hemisphere by the anterior part of the collateral fissure.

A second longitudinal elevation, constant and much more conspicuous than the collateral eminence and separated from the latter by a groove, forms the inner part of the floor and the adjoining mesial wall of the inferior horn of the lateral ventricle. This elevation, known as the **hippocampus**, is the most prominent feature of the horn and curves downward and inward to the extreme lower limit of this part of the ventricle. It is due to the early invagination of the hemisphere by the hippocampal fissure. The lower end of the hippocampus is distinctly broader and somewhat flattened and marked by a number of oblique shallow furrows and intervening low radiating ridges (**digitationes hippocampi**). These confer on the upper surface and especially on the outer rounded border of the elevation, a corrugated and notched appearance, (Fig. 1004) which suggests a fancied resemblance to a paw, the lower end of the projection being known as the **pes hippocampi**. The upper surface and the anterior and lateral border of the pes are free and well defined, but its deeper surface and inner border, to a large extent, are blended with the surrounding parts of the hemisphere. The minute structure of the hippocampus is described with that of the cerebral cortex (page 1181).

FIG. 1004.



Inferior horn of left lateral ventricle, viewed from above.

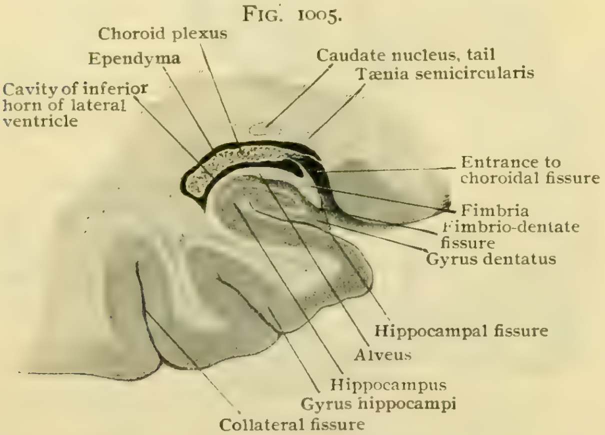
The dorso-mesial aspect of the hippocampus is overlaid by a white flattened band, the **fimbria** (**fimbria hippocampi**), which, although bearing a special name, is the direct prolongation of the posterior crus of the fornix, continued from the lateral angle of the corpus fornicis into the inferior horn. Its concave mesial margin is smooth, rounded and free, whilst its sinuous lateral border is thin and sharp and gives attachment throughout its entire length to the delicate ependymal layer which completes the mesial wall and thus closes in the descending horn (Fig. 1005). Above narrow and then broader, on reaching the pes the fimbria becomes abruptly reduced to a narrow strand, which may be followed along the inner margin of the pes to the uncus where it ends. Traced upward the fimbria passes without interruption into the posterior limb of the fornix, of which, as already noted, it is the direct downward prolongation. Beginning in the uncus, the fimbria continually receives accessions of fibres from the underlying hippocampus, with which it is closely united along its deep surface, and therefore increases in bulk as it ascends towards the body of the fornix.

When the structures within the inferior horn of the lateral ventricle are viewed in their undisturbed relations (Fig. 1002), little of the hippocampus and nothing of the fimbria are seen, as these parts are hidden by the overlying mass of vascular tissue constituting the choroid plexus, which is not confined to the body of the ventricle, where its connections have been already described, but follows the descending

horn to its lower end. On turning aside the vascular fringe, its relations to this part of the ventricle will be found to be identical with those exhibited in the body of the ventricle, since here, as there, the vascular complex is everywhere covered by the thin layer of reflected ependyma and, therefore, excluded from actual entrance into the ventricular space. Tracing the line of attachment of the reflected ependyma, which alone represents the true ventricular wall closing the crescentic choroidal fissure along the dorso-mesial aspect of the inferior horn, it will be found to be continuous with the thin lateral edge of the fimbria throughout the entire length of this attenuated margin, just as it is connected with the fornix within the body of the ventricle. Passing from this line of attachment (**tænia fimbriæ**) over all the villous projections of the choroid plexus, the reflected ependyma returns to the thicker ventricular wall, which it joins along the mesial border of the roof. Thence the ependyma remains in close contact with the remaining parts of the walls of the inferior horn, all the surfaces of which, including those formed by the hippocampus and the collateral eminence, it covers. From these relations (Fig. 1005) it follows that the fimbria in large part is excluded, as are some other parts of the fornix, from the ventricle, only that portion of its surface which extends from its sharp lateral border to the underlying hippocampus forming, strictly regarded, a part of the ventricular wall. The rounded mesial border and the dorsal surface of the fimbria belong to the free mesial surface of the hemisphere.

The **dentate gyrus** (**fascia dentata**) is part of an atrophic convolution belonging to the rhinencephalon (page 1151), and as such belongs systematically to that division of the hemisphere. Since, however, it is closely associated with the structures found within the inferior horn of the lateral ventricle, its description has been deferred until this place. The dentate gyrus lies on the mesial surface of the hemisphere, but is so hidden behind the hippocampal gyrus that it is satisfactorily displayed only after the overhanging parts of the thalamus and cerebral crura are removed. On cutting away these structures and drawing downward the hippocampal gyrus, a narrow band of gray matter, notched and corrugated by numerous minute transverse furrows, is seen protruding between the free rounded mesial border of the fimbria above and the hippocampal fissure below (Fig. 992). This band is the gyrus dentatus. On examining frontal sections passing through the inferior horn of the lateral ventricle (Fig. 1005), the relations of the dentate gyrus will be appreciated. In such preparations the gyrus appears as the free, somewhat thinned off edge of cortical gray matter, which is pushed to the surface just below the choroidal fissure through which the pial tissue invaginates the ventricular wall to gain a seeming entrance to the inferior horn. Between the fimbria, which lies immediately above and parallel with it, and the gyrus a shallow groove, the *sulcus fimbrio-dentatus*, intervenes, whilst below it is bounded by the remains of the *hippocampal* or *dentate fissure*. The latter is no longer an evident furrow, as it was when producing the hippocampus, since it has become closed and almost completely obliterated by the apposition of the bordering cortex.

FIG. 1005.



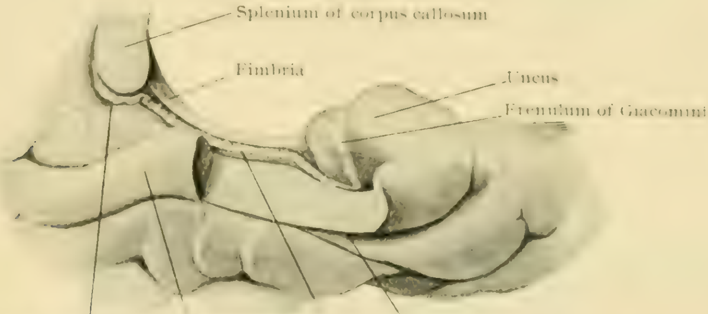
Frontal section of part of left hemisphere passing through lower end of inferior horn of lateral ventricle. × 2.

Traced forward, the gyrus dentatus gradually leaves the fimbria and passes deeply along the inner side of the uncus in connection with which it ends. The terminal part of the gyrus, somewhat reduced in size, at first bends sharply medially along

the under surface of the uncus and then winds over the inner aspect of the latter, from within outwards, as a narrow grayish band, the **frenulum of Giacomini**, which, continuing upon the upper surface of the uncus, for a short distance passes slightly backward and disappears (Fig. 1006).

Followed backward, the gyrus dentatus accompanies the fimbria towards the splenium, at the lower border of which the two structures part company, the fimbria passing to the under side of the corpus callosum, whilst the gyrus dentatus, losing its corrugations and becoming a smooth band, known as the **fasciola cinerea**, bends backward and curves around the splenium (Fig. 992) to spread out over the upper surface of the corpus callosum as the thin atrophic sheet of gray matter, the **induseum griseum** in which are embedded the fibre-strands of the longitudinal striae (page 1156). The structure of the gyrus dentatus is described with that of other parts of the cerebral cortex (page 1182).

FIG. 1006.



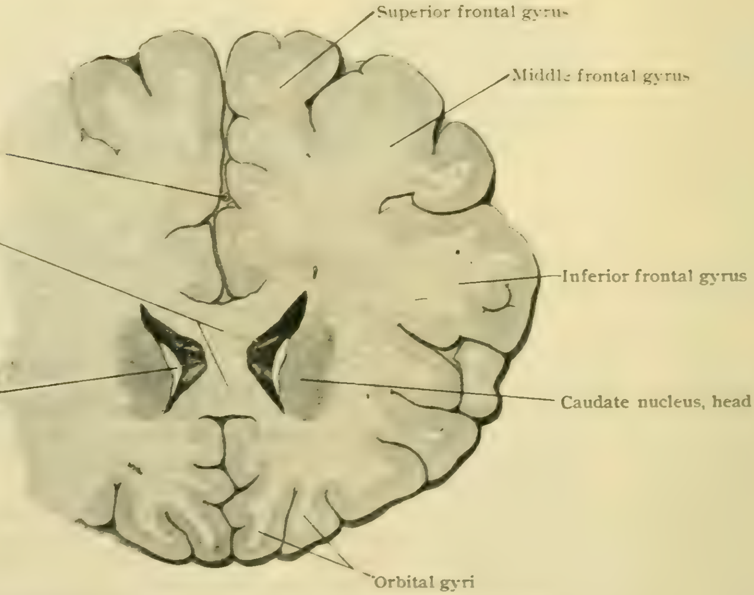
Part of left gyrus hippocampi has been cut away to expose gyrus dentatus, which is seen continuing as frenulum of Giacomini over uncus.

The fornix is to be regarded as the chief fibre-tract connecting the olfactory cortex, situated within the uncus and the hippocampus, with the thalamus. An explanation of its remarkable course as seen in the adult brain, is found in the changes which affect the position of the hippocampus during development. Reference to Figs. 1030, 1032, will recall the origin of the hemisphere (pallium) as an outgrowth from the end-brain, and, further, that the hemisphere in man early covers in the thalamus and other parts of the diencephalon and the mid-brain. For a time the thalamus is connected with the hemisphere by means of only the thin recurved under and inner wall of the pallium, the bulky tracts of white matter in which it is later embedded being for a time wanting. This same independence is retained by the thalamus, even in the adult condition, on its upper and posterior aspects, where the excessively thinned out ventricular wall alone forms the partition between the ventricle and the exterior, and where the thalamus is overlaid by, but not in contact with, the hemisphere. On breaking through this partition, as after removal of the velum interpositum, the thalamus may be directly reached by passing beneath the splenium. When a definite mesial surface of the hemisphere becomes developed, an area along the inferior margin of this aspect becomes marked off by two primary grooves, which are the early choroidal fissure below and the hippocampal fissure above. The area so defined is the primary gyrus dentatus. This tract of gray matter is connected with the thalamus by the fornix, which reaches the thalamus around the front end of the choroidal fissure. In many animals, as in the rabbit, a similar relation is permanently retained, the dentate gyrus, or its equivalent, the hippocampus, being united with the thalamus by a fornix-tract which sweeps from the lower and posterior part of the pallium (hippocampus) over the roof of the third ventricle forward and downward to the basal surface of the brain (mammillary body) and thence by the *bundle of Vicq d'Azyr* to the thalamus. These primary relations are changed by the future expansion of the hemisphere, which grows not only upward and backward, but also downward to form the temporal lobe, in consequence of which the dentate gyrus and the fornix, and likewise the choroid plexus and its fissure, are carried backward, downward and forward around the thalamus into the temporal lobe, where they lie on the mesial wall of the descending horn of the lateral ventricle which has coincidently been formed. Whilst in this manner the chief mass of the primary gyrus dentatus is carried into the temporal lobe, where it becomes the hippocampus and

the definite dentate gyrus, a part of it, greatly attenuated and reduced, retains its connection with the anterior basal surface of the brain (later the anterior perforated substance), and follows the upper surface of the corpus callosum, which likewise has extended backward, into the descending horn of the lateral ventricle. These parts—the gyrus subcallosus, the longitudinal striæ, the fasciola cinerea and the gyrus dentatus of the adult brain—constitute the supracallosal gyrus, whose gray matter is an atrophic outlying part of the primary gyrus dentatus and whose connections with the basal olfactory centres are retained by the fibres of the longitudinal striæ. The fornix shares the displacement of its cortical area, the hippocampus, and is consequently carried with the latter into the descending horn of the lateral ventricle. In this manner parts which at first lay in proximity and were connected by short paths, become widely separated, with corresponding lengthening of the fibre-tracts uniting them, as illustrated in the long course of the fornix in the adult brain. Further, since the path of migration of the fornix and associated structures of the inferior horn of the lateral ventricle describes a curve, it follows that the relations of these parts become reversed, those originally lying above, in regard to adjacent structures, within the descending horn being below and vice versa.

The **posterior horn** of the lateral ventricle (**cornu posterius**), much smaller than either of the others, is an elongated diverticulum which curves backward from

FIG. 1007.



Frontal section of brain passing through genu of corpus callosum.

the body of the ventricle into the occipital lobe. In frontal sections (Fig. 1034) its form is irregularly crescentic, the convexity of its outline including the roof and the lateral wall and the concavity corresponding with the mesial wall and narrow floor. Above and to the outer side, the horn is bounded by the arching fibres of the tapetum of the corpus callosum, lateral to which lies the important thalamo-occipital or optic radiation (page 1123). The lower part of the mesial wall is modelled (Fig. 1000) by a narrow but well marked crescentic elevation, the **calcar avis,** also called the *hippocampus minor*, which is produced by the early invagination of the wall of the hemisphere by the anterior part of the calcarine fissure. On the same wall and just above the calcar avis, a second and broader, but less sharply defined, elevation (**bulbus cornu posterioris**), marks the course of the fibres of the forceps posterior as they encircle the parieto-occipital fissure in their journey to the occipital lobe.

The Internal Nuclei of the Hemisphere.

Embedded within the white matter of each hemisphere and, for the most part, completely separated from the cerebral cortex, lie certain masses of gray matter to which the name **basal ganglia** is often applied. These include: (1) the *caudate nucleus*, (2) the *lenticular nucleus*, (3) the *claustrum* and (4) the *amygdaloid nucleus*. The first two, the caudate and lenticular nuclei, are parts of the **corpus striatum,** one of the three fundamental divisions of the end-brain or telencephalon. Although almost completely separated by the intervening tract of white matter, the *internal capsule*, the caudate and lenticular nuclei are continuous for a limited distance below and in front (Fig. 1008), and together constitute a large mass composed chiefly of gray matter, that extends from the lateral ventricle almost to the cortex of the insula. Between the latter and the lenticular nucleus lies a thin tract of gray matter, the *claustrum*, whilst within the temporal lobe, above and in front of the anterior extremity of the inferior horn of the lateral ventricle, is situated the *amygdaloid nucleus*.

The Caudate Nucleus.—This mass (**nucleus caudatus**), the inner division of the corpus striatum, is well seen from the lateral ventricle, where it appears as the large and conspicuous elevation which contributes the infero-lateral wall of the anterior horn, and the outer part of the floor of the body of the ventricle. The caudate nucleus is an elongated pyriform or comet-shaped mass of gray matter, whose bulky rounded anterior end or **head** (**caput nuclei caudati**) rapidly diminishes into the attenuated and recurved **tail** (**cauda nuclei caudati**), which sweeps backward and then downward and forward within the roof of the inferior horn to the tip of the temporal lobe, where it ends in relation with the lower part of the amygdaloid nucleus.

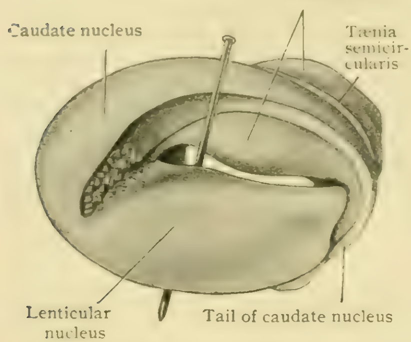
The relations of its two chief surfaces, the mesial and lateral, are best seen in frontal sections. When sectioned through its head near the anterior pole (Fig. 1007), the caudate nucleus appears as an ovoid area of gray matter which mesially bulges strongly into the lateral ventricle, but from which it is separated by the ependyma, and laterally is embedded within the white matter of the hemisphere. In sections passing a few millimeters farther back (Fig. 1009), the form of the nucleus has become somewhat changed, its inner convex surface being more extensive and its outer one, now somewhat concave, being serrated by the invasion of obliquely horizontal stripes of white matter due to the appearance of the anterior strands of the internal capsule. In the plane under consideration, these strands are not continuous but interspersed with stripes of gray matter, which below still connect the caudate with the laterally situated lenticular nucleus and produce the coarse striation from which the entire mass, the corpus striatum, derives its name.

In sections passing through the body of the ventricle (Figs. 1010, 1025), from the plane of the foramina of Monro backward, the caudate nucleus is much reduced in size, whilst, on the contrary, the lenticular nucleus, as well as the thalamus, become more conspicuous. The internal capsule, being now well established, appears as a large oblique tract of white matter, which completely separates the two parts of the corpus striatum and lies to the outer side of the thalamus (Fig. 1008). By reason of the recurved course of its attenuated tail, in horizontal sections, as well as in frontal ones passing in front of the splenium, the caudate nucleus is twice cut, one cross-section of the nucleus appearing above in the lateral wall of the body of the ventricle and the other in the roof of the inferior horn (Fig. 967).

The Lenticular Nucleus.—This division of the corpus striatum (**nucleus lentiformis**) is a wedge-shaped mass of gray matter, broken by laminæ of white, that lies bordered by the internal capsule mesially, and laterally is separated from the cortex of the insula by a narrow tract of white matter containing a thin stratum of gray substance, the claustrum. The lenticular nucleus reaches neither as far forward nor as high as the caudate nucleus, and lies lateral to both the latter and the thalamus, separated from them respectively by the anterior and posterior limbs of the internal capsule. Its dorso-mesial surface, when seen in frontal sections, is directed from above downward and inward; in transverse sections (Fig. 1011) this surface is replaced by an antero-mesial and a postero-mesial face in correspondence with the limbs of the internal capsule. Its slightly convex lateral surface is approximately

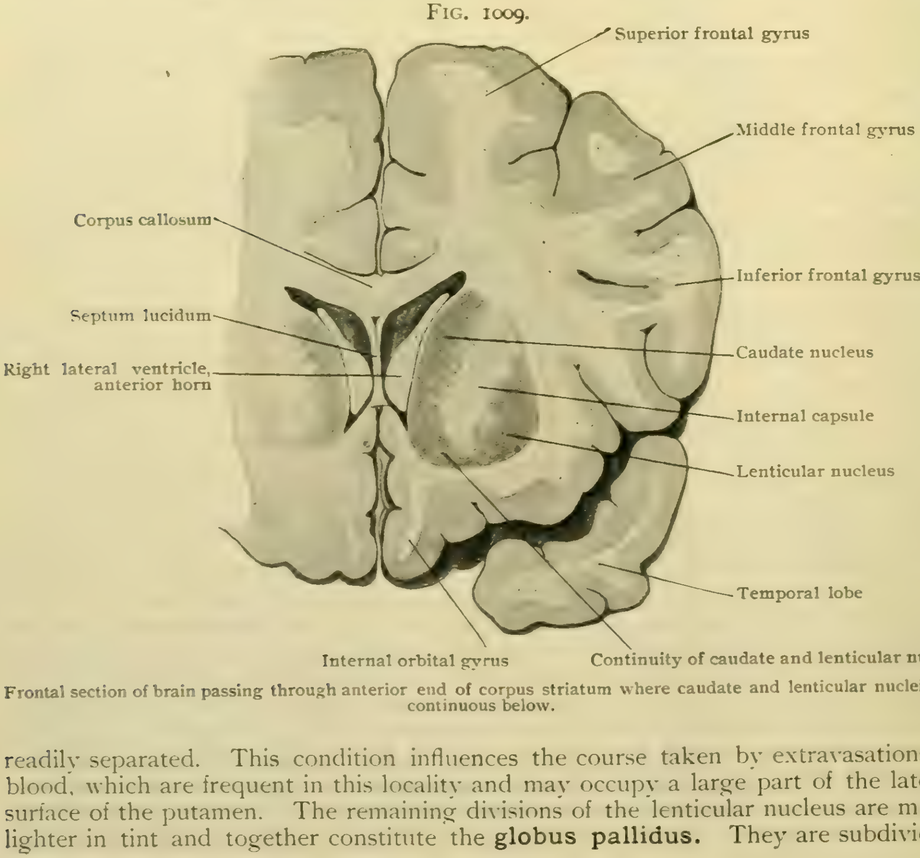
vertical and in immediate contact with a thin sheet of white matter, the *external capsule*, which separates the nucleus from the claustrum. Its ventral surface is horizontal and only feebly curved and is continuous in front with the caudate nucleus and farther backward, about its middle, with the anterior perforated substance on the basal surface of the brain. The lenticular nucleus is unequally subdivided by two thin concentric sheets of white matter, the **external** and **internal medullary laminæ,** into three segments. The outer of these, the **putamen,** is much the largest and occupies the base of the nucleus, being bounded by the external capsule laterally and by the external medullary lamina mesially. Of its two somewhat rounded ends, the anterior is the broader and extends farther forward and alone joins the caudate nucleus of which it morphologically is a part (page 1169). The putamen is the most conspicuous part of the lenticular nucleus, not only on account of its size but also by reason of its darker color, in which respect it corresponds with the caudate nucleus. This contrast depends less upon the actual pigmentation of the cells of the putamen than upon the lighter color of the other zones of the nucleus. In consequence of the small number of fibres entering the external capsule from the putamen, the attachment between the latter and the capsule is relatively loose and the two structures may be

FIG. 1008.



Reconstruction of corpus striatum and thalamus; lateral aspect; probe lies in space occupied by internal capsule. Drawn from Steger model.

FIG. 1009.



Frontal section of brain passing through anterior end of corpus striatum where caudate and lenticular nuclei are continuous below.

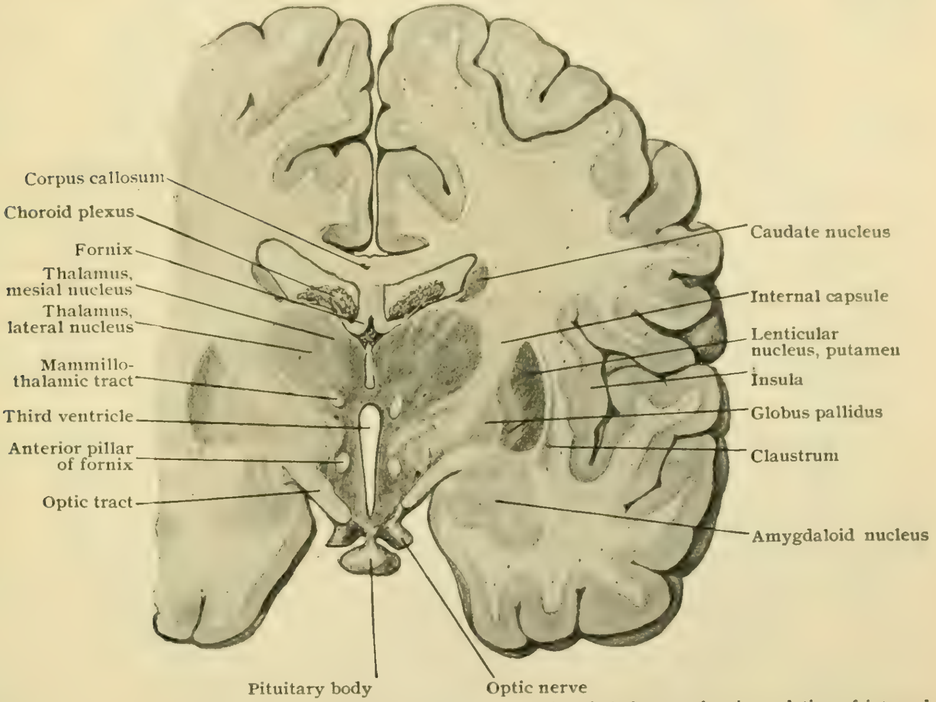
readily separated. This condition influences the course taken by extravasations of blood, which are frequent in this locality and may occupy a large part of the lateral surface of the putamen. The remaining divisions of the lenticular nucleus are much lighter in tint and together constitute the **globus pallidus.** They are subdivided

by the internal medullary lamina and form the edge of the wedge, lying in contact with the internal capsule. Although composed chiefly of gray matter, all these segments of the nucleus, but particulary the inner two, are traversed by numerous strands of nerve-fibres which break the continuity of the gray substance and produce an appearance of radial striation.

The **structure of the corpus striatum** varies in its several parts, that of the caudate nucleus and the putamen being almost identical, whilst that of the globus pallidus, although similar in both zones, differs from the histological make-up of the other parts. The close resemblance of the caudate nucleus and the putamen corresponds to their early common origin, since at first they constitute a single mass and become partially separated by the ingrowth of the fibres forming the anterior part of the internal capsule.

The *caudate nucleus* is invested throughout the greater part of its periphery by a dense layer of fibres, the stratum zonale, which includes fibres passing both to

FIG. 1010.



Frontal section of brain passing through caudate and lenticular nuclei and thalamus, showing relation of internal capsule to internal nuclei.

and from the nucleus. The nerve-cells are, for the most part, rather small in size and stellate or fusiform in shape and provided with numerous dendrites beset with minute irregularities. They are chiefly cells of type I, although many of the second type are encountered, whose axones are limited to the gray matter and are not prolonged as nerve-fibres (Kölliker).

The *putamen* is invested on its two sides, particularly on the mesial one, with a fibre-layer derived from the external medullary lamina and the external capsule, the fibres being chiefly such as enter the nucleus from other centres by way of the medullary layer. In addition to nerve-cells of round or stellate form, Kölliker describes those of distinctive appearance possessing a slender fusiform body and dendrites few in number but of unusual length.

The *globus pallidus* owes its characteristic color to the light yellowish tint of the pigment within its cells and to the large number of medullated nerve-fibres which traverse its substance, especially its inner zone. The nerve-cells are mostly small and stellate, possessing numerous short but richly branched dendrites.

The Connections of the Corpus Striatum.—Much uncertainty prevails as to the details of the connections of the several parts of the corpus striatum and little is known regarding the function of these nuclei, notwithstanding their size ; certain general principles, however, may be accepted as established. The comparative studies of Gehuchten, Sala and others, and especially of Edinger, emphasize that the corpus striatum is to be considered as supplemental to the cortical substance, in the lower vertebrates in which the cortex of the cerebral mantle is feebly developed constituting the chief mass of cortical gray matter, and in the mammals and man being subservient to the overshadowing cortex of the hemisphere. Such being the warranted presumption, it is to be anticipated that the striate body both receives fibres conveying sensory impulses and gives off fibres (perhaps motor in function) originating from its cells, these latter tracts constituting the *strio-thalamic radiation.*

The **centripetal** or **afferent paths** probably include : (1) the *tegmento-striate fibres*, which are continued chiefly from the mesial fillet, and perhaps also from the red nucleus and subthalamic region, by way of the internal capsule, to end around the cells of the putamen and head of the caudate nucleus ; (2) the *thalamo-striate fibres*, already mentioned in connection with the thalamus (page 1123), which pass from the thalamus either by way of the internal capsule directly to the caudate nucleus, or by way of the ansa lenticularis to the putamen or, traversing the medullary laminæ, to the caudate nucleus. No doubt many of the fibres which enter the lenticular nucleus do not end within the latter, but traverse its substance as part of their path to the cerebral cortex.

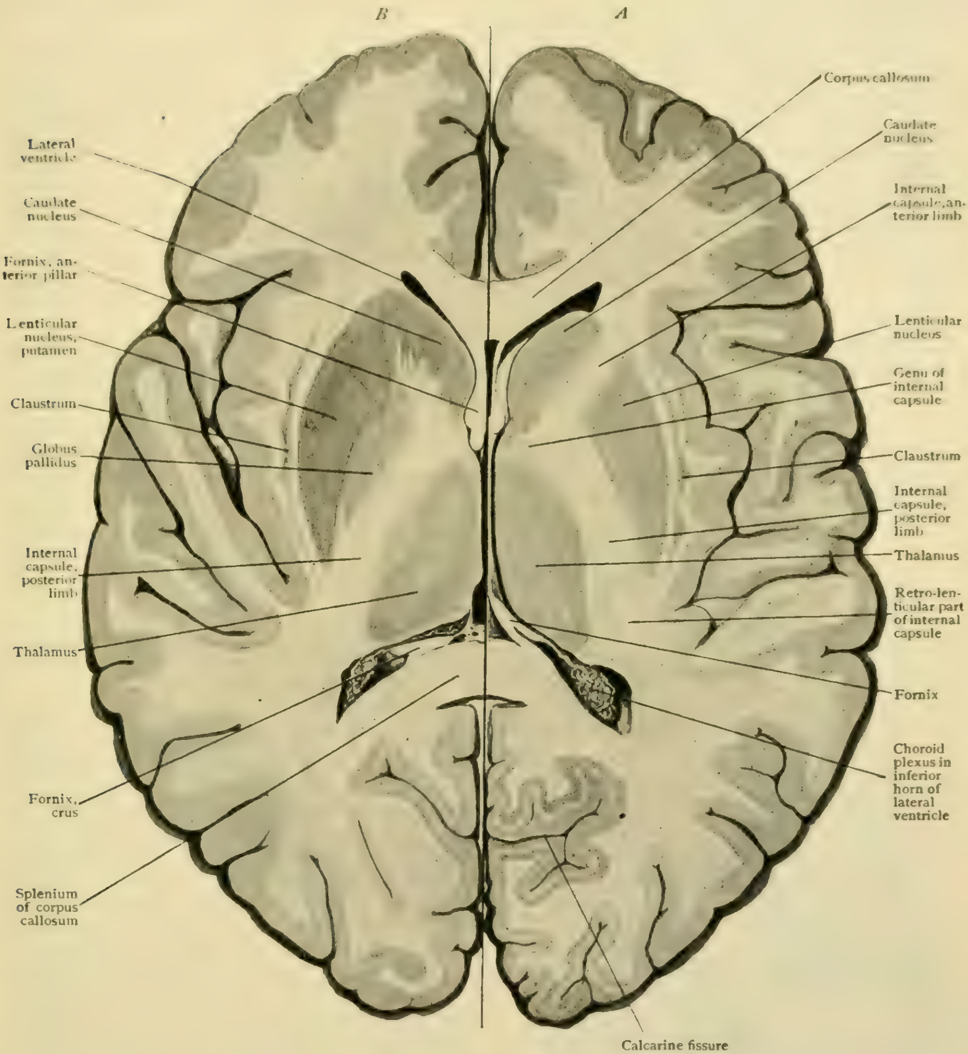
The **centrifugal**, or **efferent fibres**, which arise from the cells of the corpus striatum include : (1) the *strio-thalamic fibres*, passing from the major divisions of the striate body, which comprise (*a*) those from the caudate nucleus to the thalamus direct ; (*b*) those which traverse the internal capsule and the medullary laminæ and, joining fibres from the putamen, pass by way of the ansa lenticularis to the thalamus ; (*c*) those from the putamen which reach the thalamus by passing partly by way of the globus pallidus and partly, in greater numbers, by means of the ansa lenticularis. (2) *Strio-peduncular fibres*, well represented in the brains of the lower animals as the continuation of the basal tract of the fore-brain (Edinger), which pass from the caudate nucleus, and probably from the lenticular nucleus also, into the sub-thalamic region and the cerebral peduncle, within the latter forming the stratum intermedium closely related to the substantia nigra. Whether cortico-striate fibres, extending from the cerebral cortex to the corpus striatum, exist in man is uncertain, Dejerine denying their presence, whilst Edinger regards the presence of a meagre number of such bundles as established.

The Claustrum.—The claustrum is a thin lamina of gray substance embedded within the white matter intervening between the lateral surface of the putamen and the cortex of the island of Reil. Its mesial surface is smooth and parallel with the outer aspect of the putamen, from which it is separated by the thin tract of white matter constituting the **external capsule.** Its lateral surface presents a series of elevations and depressions which in a general way repeat the contour of the gray cortical lamina of the insula, the intervening layer of white matter being sometimes called the *capsula extrema.* Seen in horizontal sections (Fig. 1011), the claustrum fades away both in front and behind ; in frontal sections (Fig. 1010), however, whilst it gradually disappears above, below the claustrum materially thickens and mesially becomes continuous with the anterior perforated substance. Upon comparative and developmental grounds, the claustrum must be regarded as a separated portion of the corpus striatum. Its nerve-cells are, for the most part, small and either stellate or fusiform in outline. Nothing is known with certainty as to the course or connection of its fibres.

The Amygdaloid Nucleus. — This structure (**nucleus amygdalae**) comprises a considerable rounded mass of gray substance (Fig. 1010) which occupies the fore-part of the temporal lobe and lies in close proximity with the uncus, overlying the extremity of the inferior horn of the lateral ventricle. Anteriorly it is continuous with the cortical gray matter of the temporal lobe as a thickened portion of which it may be regarded. Its lower part receives the tail of the caudate nucleus and close to this, the tænia semicircularis (page 1162), which accompanies the recurved nuclear tail in its descent within the roof of the inferior horn. The nucleus approaches, if indeed it does not touch, the anterior perforated substance, and above comes into intimate relations with the lenticular nucleus. It is highly probable that the nucleus amygdalæ forms, along with the uncus and the hippocampus, a part of the olfactory cortex (Dejerine).

The Internal Capsule.—Repeated mention has been made of the important tract of white matter bearing the name of internal capsule (**capsula interna**); its description, therefore, may be appropriately undertaken at this place. It is a broad, compact band of nerve-fibres which passes between the three large basal ganglia, namely, the caudate and the lenticular nuclei and the thalamus. Although the details of the internal capsule vary with differences both of direction and of position of the

FIG. 1011.



Horizontal sections of brain, *A* at higher level than *B*, which passes through lower part of corpus striatum where caudate and lenticular nuclei are continuous; relations of limbs of internal capsule to internal nuclei seen on right side.

planes of section, its general relation to these three masses of gray matter is constant, the caudate nucleus and the thalamus always lying to its inner side and the lenticular nucleus to its outer aspect. When exposed by frontal sections passing through the anterior part of the lateral ventricles (Fig. 1010), the internal capsule appears as a broad, oblique stripe, extending from above downward and inward, bounded by the large caudate nucleus mesially, the lenticular nucleus laterally, and below by the gray substance establishing continuity between the two nuclei.

Seen in frontal sections passing some distance behind the preceding section, whilst the capsule is limited laterally by the lenticular nucleus, its mesial boundary now includes the caudate nucleus, the tænia semicircularis and the thalamus. Still farther back (Fig. 968), the internal capsule is bounded internally in addition by the subthalamic structures and becomes continuous below with the crusta of the cerebral peduncle. An upper and a lower part of the capsule are therefore recognized, the former—between the lenticular nucleus on the one side, and the caudate nucleus on the other—is known as the *thalamic region* (**regio thalamica capsulae internae**), whilst that between the lenticular nucleus and the subthalamic structures is termed the *subthalamic region* (**regio subthalamica**).

Viewed in horizontal sections (Fig. 1011, *A*), the capsule appears not only much more extensive, but is seen to consist of two mesially converging parts, a shorter **anterior limb** (**pars frontalis**) and a longer **posterior limb** (**pars occipitalis**). The two limbs form an angle which opens outward and encloses on two sides the gray triangle of the lenticular nucleus. The junction of the two mesially converging limbs forms the knee, or **genu,** of the internal capsule which points inward and lies opposite the tænia semicircularis, between the caudate nucleus and the thalamus. At deeper planes (Fig. 1011, *B*), passing through the level of the continuity between the two parts of the corpus striatum, the anterior limb is greatly reduced in length or entirely disappears, the posterior one being prolonged into the cerebral peduncle.

The importance of the internal capsule will be appreciated when its function as the great pathway connecting the cerebral cortex with the lower lying centres is recalled. Its fibres, both corticipetal and corticifugal, after passing beyond, or before coming under the restraint of the boundaries of the capsule, as the case may be, radiate to and from all parts of the hemisphere, and in this manner form the striking fan-shaped fibre-mass known as the **corona radiata,** which continues the internal capsule upward to the cerebral cortex. The radiating strands of this great tract interlace with the radiation of the corpus callosum and thereby contribute a large part of the fibres composing the oval centre of white matter within the hemisphere.

FIG. 1012.

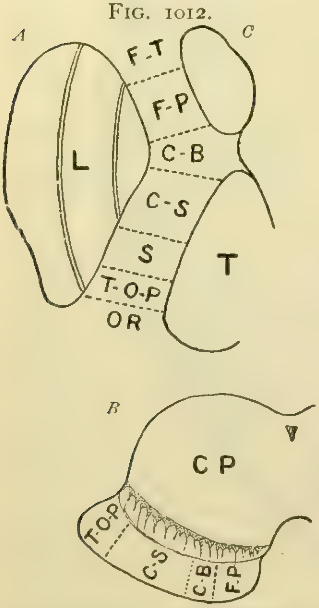


Diagram showing relative positions of chief tracts in internal capsule (*A*) and in crusta of cerebral peduncle (*B*); *F-T*, fronto-thalamic; *F-P*, fronto-pontile; *T-O-P*, temporo-occipito-pontile; *C-B*, cortico-bulbar; *C-S*, cortico-spinal; *S*, tegmental sensory; *OR*, optic radiation.

The **anterior limb** of the internal capsule (**pars lenticulocaudata**) includes the front third of the tract and extends from the genu forward and outward. It contains fibres passing both toward and away from the cortex. Its **corticipetal fibres** are: (1) the *thalamo-frontal,* which pass from the thalamus by way of its frontal stalk through the anterior limb of the internal capsule and the corona radiata to the cortex of the frontal lobe; (2) the *thalamo-striate,* which also pass from the thalamus into the internal capsule and proceed to the caudate and lenticular nuclei. The **corticifugal fibres** include: (1) the *fronto-pontile,* which arise in the cortex of the frontal lobe and descend by way of the corona radiata, the anterior limb of the internal capsule, the crusta of the cerebral peduncle and the ventral tracts of the pons to end around the cells of the pontile nucleus as links in the connection between the cerebral and the cerebellar cortex (page 1094); (2) the *fronto-thalamic,* which extend from the cortex of the frontal lobe to the thalamus; and (3) the *strio-thalamic,* which proceed from the caudate and lenticular nuclei to the thalamus.

The **posterior limb** of the internal capsule (**pars lenticulothalamica**) extends backward, outward and downward from the genu, and includes the remaining two-thirds of the tract. Its hind part extends beyond the posterior limit of the lenticular nucleus, hence the posterior limb is subdivided into a *lenticular* and a *retrolenticular portion.* As does the anterior limb, so also does the posterior limb of the capsule contain both corticipetal and corticifugal fibres.

The **lenticular portion** includes **corticipetal fibres**: (1) the *thalamo-cortical,* which issue from the lateral and lower aspect of the thalamus, traverse the internal capsule and to a considerable

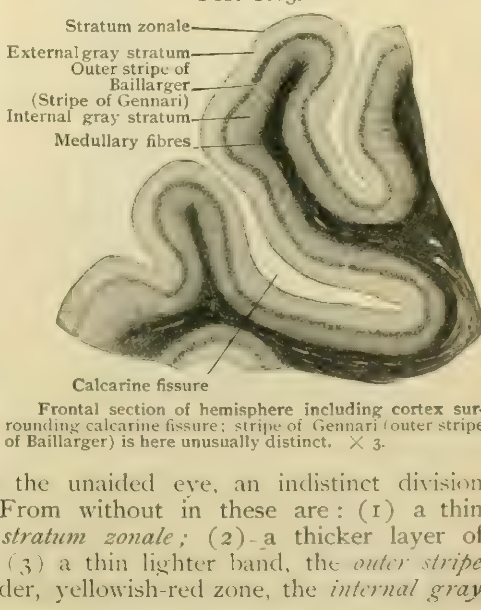
number, the lenticular nucleus and the external capsule and proceed to the cortex of the hind part of the frontal and of the parietal lobe; and (2) probably some *thalamo-lenticular* fibres which pass from the thalamus to the lenticular and, perhaps, the caudate nucleus. The **corticifugal fibres** include: (1) the important motor *cortico-bulbar* and *cortico-spinal* tracts, collectively often called the *pyramidal tracts*, which descend from the precentral (Rolandic) cortical region through the corona radiata and the fore-part of the posterior limb of the internal capsule into the crusta of the cerebral peduncle and thence to the appropriate levels of the brain-stem or of the spinal cord. A tract supplementary to the pyramidal motor paths, the *cortico-rubral fibres*, must be mentioned. These arise from the cortex (perhaps of the parietal lobe) and descend through the lenticular portion of the posterior limb to the mid-brain where they end in relation with the red nucleus. (2) The *cortico-thalamic* fibres, which converge from the cerebral cortex to the thalamus. The **retrolenticular portion** of the posterior limb is traversed by important **corticipetal fibres** concerned in conveying impressions of special sense, as (1) those of the *optic radiation*, which, issuing as the occipital stalk, connect the thalamus and the lateral geniculate and the superior quadrigeminal body with the occipital cortex; and (2) those of the *auditory radiation*, which link together the mesial geniculate and the inferior quadrigeminal body with the auditory cortical area in the temporal lobe. The **corticifugal fibres** are represented by (1) the *temporo-occipito-pontile* tracts, which pass from the cerebral cortex through the retrolenticular portion of the capsule into the crusta of the cerebral peduncle and thence to the pontile nucleus within the ventral part of the pons; and (2) *cortico-thalamic* fibres, which course in reverse order through the optic radiation to end within the thalamus and lateral geniculate body.

The **relative positions** of the longer tracts composing the internal capsule, as seen in horizontal sections, are, in a general way, indicated schematically in Fig. 1012. The anterior limb is shared, from before backward, by the fronto-thalamic and the fronto-pontile tracts in the order named. The genu is appropriated by the cortico-bulbar tracts, the facial fibres lying immediately in advance of the hypoglossal. The succeeding part of the posterior limb, approximately one-third, affords passage to the cortico-spinal or pyramidal tracts. Next follows a narrow segment devoted to the tegmental sensory tracts, behind which the occipito-temporo-pontile tract occupies a small area, the last part of the retrolenticular field being taken up by the optic radiation.

STRUCTURE OF THE CEREBRAL CORTEX.

The surface of the hemispheres is everywhere clothed with a thin continuous stratum of cortical gray matter, which encloses the white medullary substance composed of the interlacing tracts of nerve-fibres. This cortical sheet varies in thickness not only in the same area, being thicker over the summit than at the sides of the convolutions or at the bottom of the bounding fissures, but in different regions of the hemisphere. Its average thickness is about 3 mm., but where it borders the upper end of the Rolandic fissure, particularly in the paracentral lobule, this increases to over 5 mm., whilst over the frontal and occipital poles the thickness of the cortex is reduced to almost 2 mm. The entire superficial extent of the cortex of the two hemispheres has been estimated to be about 2000 sq. cm., of which scarcely one-third is exposed surface, the remainder being sunken.

Fig. 1013.



Frontal section of hemisphere including cortex surrounding calcarine fissure; stripe of Gennari (outer stripe of Baillarger) is here unusually distinct. × 3.

On examining sections of the fresh brain, the cortex does not appear uniformly tinted, but exhibits, even to the unaided eye, an indistinct division into alternate light and dark layers. From without in these are: (1) a thin peripheral layer of whitish color, the *stratum zonale;* (2) a thicker layer of grayish hue, the *external gray stratum;* (3) a thin lighter band, the *outer stripe of Baillarger;* and (4) a somewhat broader, yellowish-red zone, the *internal gray*

stratum—four layers being more or less clearly recognizable. In certain localities, as in the precentral convolution, the inner gray lamina is subdivided by an additional white line, the *inner stripe of Baillarger.* In the vicinity of the calcarine fissure, particularly in the adjacent part of the cuneus, the outer stripe of Baillarger, whilst narrow, is unusually distinct and confers, therefore, a characteristic appearance upon the cortex of this region (Fig. 1013). The band in this location receives the name of the *stripe of Gennari*, or the *stripe of Vicq d'Azyr.* In recognition of the priority of description, Gennari's name is sometimes applied to the external stripe of Baillarger wherever found. The significance of these light colored strata will be pointed out in connection with the intimate structure of the cortex, suffice it here to note that the stripes of Baillarger correspond to zones in which the felt-work of horizontal cell-processes is unusually dense, the stratum zonale corresponding to a compact layer of fibres running parallel with the surface. Occasionally a condensation of tangential fibres immediately beneath the stratum zonale produces the appearance of an additional light line, which in honor of its discoverer, is known as the *stripe of Bechterew.*

The essential histological elements of the cerebral cortex are the nerve-cells and the nerve-fibres. The importance of the former is evident when their three-fold activity is recalled—(1) as receptors of corticipetal impulses, (2) as distributors of the impressions so received to other parts of the brain, and (3) as originators of corticifugal impulses which control the nuclei from which immediately arise the motor nerves. No single method of preparation suffices to display satisfactorily both groups of structural elements, for when stains are employed which best bring out the cells, the fibres are inadequately shown; and, conversely, when methods adapted for the demonstration of the fibres are followed, the cells are but imperfectly displayed. It is advantageous, therefore, to study the histological details of the brain by more than a single method, combining the results obtained by the use of cellular stains with those yielded by procedures exhibiting the fibres. Among the latter, the well known method of Weigert, or its modifications, has been of great service in extending our knowledge concerning the various fibre-tracts. The methods of silver impregnation introduced by Golgi, although not producing true staining but only incrustations on the cell and its processes, have materially advanced our knowledge concerning the form of the cell-bodies and the number and extent of the processes of the neurones.

FIG. 1014.

Diagram showing constituents of cerebral cortex; cells in the right half, fibres in left half of figure; *A*, *B*, large and small pyramidal cells; *C*, polymorphic cells; *D*, cell of Martinotti; *E*, cell of type II; *F*, association cell; *1*, *1*, corticipetal fibres; *2*, *2*, corticifugal fibres (axones of pyramidal cells); *N*, *N*, neuroglia cells.

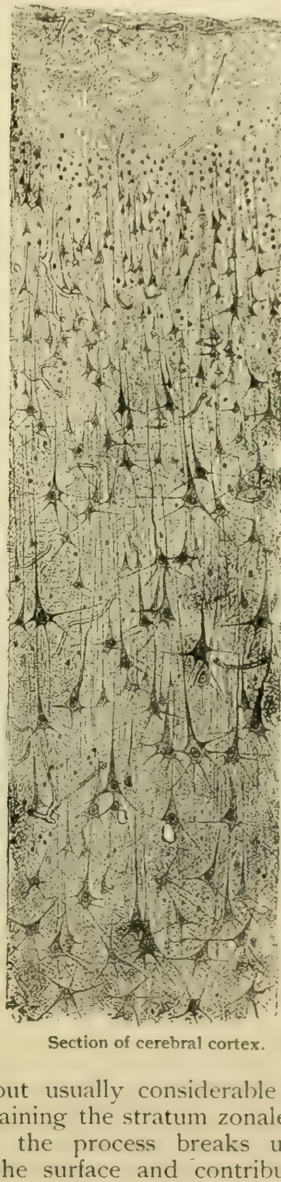
Whilst varying as to details in different regions, the cerebral cortex presents a general plan of structure which may be considered: (*a*) in relation to the nerve-cells and (*b*) in relation to the nerve-fibres.

The Nerve-Cells of the Cortex.—When sections cut perpendicular to the surface of the convolution are stained with basic stains (Fig. 1015) or prepared after silver impregnation (Fig. 1016), the cerebral cortex exhibits four layers,

which, from without inward, are: (1) the stratum zonale, (2) the layer of small pyramidal cells, (3) the layer of large pyramidal cells, and (4) the layer of polymorphic cells. Although each presents characteristics which are distinctive, with the exception of the junction between the first and second layers where the change is well defined, no sharp demarcation separates the strata, each passing insensibly into the adjoining layer. Neither are the modifications which distinguish the cortex of certain regions abruptly assumed, one type of cortical structure being gradually replaced by another without sudden transition.

The **stratum zonale,** also known as the *molecular stratum*, underlies the pia and measures about .25 mm. in thickness. The layer contains few nerve-cells and appears subdivided into (*a*) a narrow peripheral zone, from .010—.030 mm. in width, composed of a subpial condensation of neuroglia and (*b*) a deeper zone characterized by numerous fibres or processes, which course parallel to the surface, and a meagre number of nerve-cells whose most distinctive representatives are small fusiform elements (*Cajal's cells*) provided with long tangentially directed processes. The latter give off short collaterals, which ascend towards the surface, and intermingle with the numberless terminal filaments derived from the peripherally coursing processes of the pyramidal and other cells lying at deeper levels and from the corticipetal fibres which continue from the white core of the gyrus into the outermost layer of the cortex.

FIG. 1015.



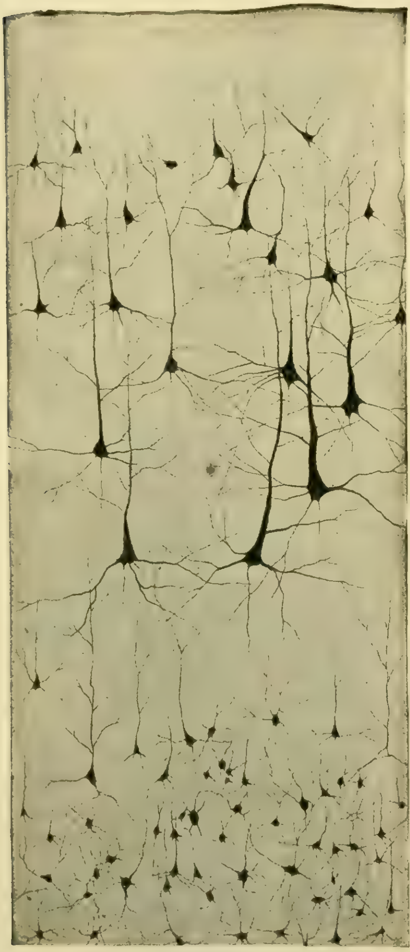
Section of cerebral cortex. × 90.

The **layer of small pyramidal cells** is marked off from the stratum zonale, which it about equals in thickness, with some distinctness since, in contrast to the last-mentioned zone, it contains very many cells. These, as indicated by the name of the stratum, are of small size (.007—.010 mm.) and pyramidal form, at least in the deepest part of the layer. In the superficial part the cells are rounded or irregularly triangular, but they assume the distinctive pyramidal outline as they approach the subjacent layer, whose elements they resemble in possessing apical and lateral processes.

The **layer of large pyramidal cells** contains the most distinctive neurones of the cerebral cortex. It measures usually about 1.25 mm. in thickness, but in some localities much more, and blends with the adjoining layers without sharp boundaries. The cells increase in size but diminish in numbers as they are traced from the second layer inward, the largest (from .020—.040 mm. in width) and most characteristic lying in the deepest part of the stratum. The typical **pyramidal cell** possesses a conical body, triangular in section, the apex of which is continued into a long tapering dendrite, the *apical process*, which extends toward the periphery for a variable but usually considerable distance, depending upon the position of the cell. Upon gaining the stratum zonale, towards which the apical dendrite is always directed, the process breaks up into a number of end-branches that run parallel with the surface and contribute to the fibre-complex of the outer layer. During its journey to the surface, the apical dendrite gives off an uncertain number of branches that continue horizontally and,

with the collaterals and similarly directed processes from other cells, take part in producing the felt-work giving rise to the outer stripe of Baillarger. From the deeper or basal surface of the cell arises the delicate centrally directed *axone*, which, penetrating the intervening fourth layer, acquires a medullary coat and enters the white core of the convolution as one of the component nerve-fibres. The axone gives off one or more collaterals which, after a shorter or longer course, establish relations with other and often remote cells. In addition to the two chief processes, the peripherally directed apical dendrite and the centrally coursing axones, a variable number—from four to twelve—of secondary *lateral dendrites* spring from the basal angles of the cell. These processes usually divide dichotomously, each succeeding pair of branches in turn splitting into twigs, until the dendrite is resolved into an end-brush of fibrillæ which aid in producing an intricate felt-work of finest threads. Each pyramidal cell contains a conspicuous spherical or ellipsoidal nucleus, within which a distinct nucleolus is usually distinguishable. The cytoplasm exhibits a striation and, in addition to the masses of tigroid substance, the Nissl bodies, a mass of brownish pigment granules. The larger pyramidal cells are surrounded by an evident pericellular lymph-space.

Fig. 1016.



Nerve-cells of cerebral cortex as seen after silver impregnation. × 90. Drawn from preparation made by Professor T. G. Lee.

The **layer of polymorphic cells** includes a large number of small nerve-cells, from .008—.010 mm. in diameter, whose forms vary greatly, irregular, spherical, triangular, stellate and fusiform elements being present. Small pyramidal cells are also often seen within this layer. In contrast to dendrites of the typical pyramidal cells, those of the polymorphic elements, although peripherally directed, do not reach the stratum zonale but end before gaining the outermost layer. Their axones pass into the subjacent fibre-layer. The radial disposition of the groups of fibres within the deepest stratum of the cortical substance limits the polymorphic cells chiefly to the interfascicular areas, within which the cells consequently appear arranged in a somewhat columnar order.

Within the deeper layers of the cortex, therefore among the polymorphic and the pyramidal elements, two additional varieties of nerve-cells are encountered. These are the cells of Martinotti and the cells of Golgi.

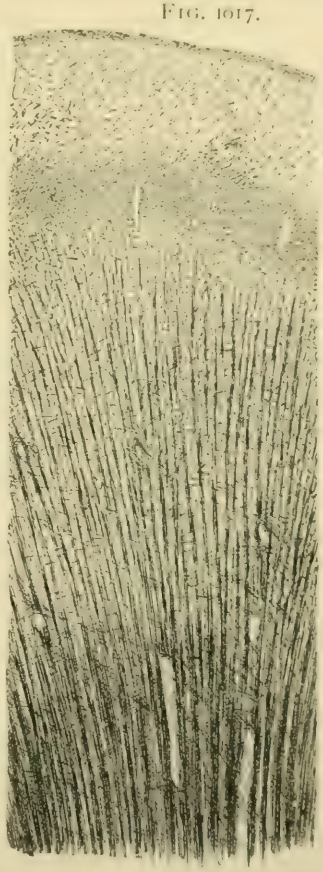
The **cells of Martinotti** are of small size and triangular or spindle-form in outline and particularly distinguished by the unusual direction of their axones. These processes pass towards the surface and within the stratum zonale divide into branches, which are continued horizontally in the felt-work of tangential fibres. As

in other parts of the central nervous system, so too in the cerebral cortex there is found a sprinkling of **Golgi's cells** of type II. Although both dendrites and axones of these cells undergo elaborate arborization, the axone is confined to a limited territory in the vicinity of the cell and, therefore, never reaches the stratum zonale.

Neuroglia cells are present in all parts of the cerebral cortex and, whilst in a general way they send fibrils in all directions between the nervous elements, which they then support, the arrangement of the fibrillæ is fairly definite in certain strata. Thus within the subpial condensation of the neuroglia, the glia cells send most of their processes as inwardly directed brushes. The cells within the deeper part of the cortex give off their processes in two chief groups, one extending towards the periphery and the other towards the white core.

The Nerve-Fibres of the Cortex.—When viewed in suitably stained sections cut parallel with their general course, the cortical nerve-fibres do not appear as a uniform layer, but as radially disposed bundles which gradually become less distinct as they traverse the cortex and finally disappear at about the level of the outer border of the layer of large pyramidal cells. The **radial fibres** are partly afferent and partly efferent. The *corticifugal components*, which predominate, are largely the centrally directed axones of the pyramidal and the polymorphic cells which are continued as the axis-cylinders of the fibres composing the subcortical white matter. The peripherally coursing axones of the cells of Martinotti also contribute to the production of the fibre-radii. The *corticipetal constituents* of these tracts include the nerve-fibres which are derived from cells situated more or less remote from the convolution in which the fibres (their axones) end. Such, for example, are the thalamo-cortical and the tegmento-cortical fibres, as well as the many commissural fibres that arise in the opposite hemisphere and cross by way of the corpus callosum. Although for the most part the corticipetal fibres end at various levels in arborizations around the pyramidal cells, some are continued into the stratum zonale where, breaking up into horizontal fibrillæ, they assist in producing the tangential zone.

FIG. 1017.



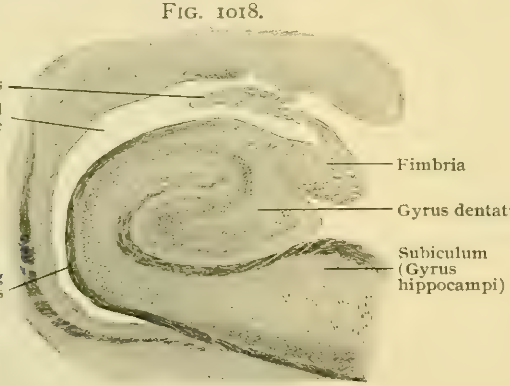
Section of cerebral cortex stained to show fibres. × 21.

The spaces between these radial bundles are occupied by a delicate interlacement, the **interradial felt-work,** which is composed in large part of the lateral and collateral processes of the cells. Within the third layer, the horizontally coursing collaterals and processes of the large pyramidal cells form a complex of unusual intricacy, which condensation gives rise to the outer stripe of Baillarger. Beyond the outer ends of the radial fibre-bundles, the intercellular ground-work is occupied by a second delicate interlacement of processes and collaterals, the **supraradial felt-work** of Edinger; whilst immediately beneath the narrow subpial neurogliar zone innumerable delicate terminal fibrillæ course horizontally and parallel with the surface and constitute the **tangential fibre-layer.** The components of this layer are the terminal branches of the dendrites of the pyramidal and polymorphic cells and the axones of the cells of Martinotti, as well as the main and secondary processes of the fusiform elements of the stratum zonale.

The evident purpose of the horizontally directed processes and collaterals being to bring into relation different cortical cells, such association tracts become evident only after the necessity for the exercise of the corresponding psychic functions has arisen. Hence in the cortex of young children the strata of horizontal fibres are very feebly developed. With the progressive advance of intellectual capacity, the association paths become correspondingly more marked, according to the suggestive observations of Kaes, the increase continuing beyond even middle life. Whether this augmentation is due to actual increase in the number of association fibres, or, as suggested by Edinger, is dependent upon the further growth and myelination of collaterals already present in an immature condition, is uncertain.

Local Variations in the Cerebral Cortex.—It has been pointed out, in prefacing the foregoing description of the structure of the cerebral cortex, that, whilst in the main certain features are common to the cortex wherever well developed, more or less evident variations occur in different localities. Such variations are, for the most part, slight and depend upon the size and number of the nerve-cells and the richness and direction of the nerve-fibres—changes which produce alterations in the relative proportions of the strata. The width of the stratum zonale is almost constant and subject to little modification, being usually well defined from the layer of small pyramidal cells. The layer of the large pyramidal cells, on the contrary, exhibits considerable variation, either in increased thickness, as in the precentral gyrus, or in diminished breadth, as in the occipital lobe. The layer of polymorphic cells is fairly uniform, but within the precentral convolutions is reduced almost to disappearance, although the pyramidal cells of the superimposed (third) layer are here of unusual size. Such variations in the histological features of the cortex are probably correlated with differences in the function of its various regions, although the exact relations between such differences are in many cases still obscure.

FIG. 1018.



Frontal section across left hippocampus and gyrus dentatus. × 2½.

Disregarding the cortical regions which are profoundly modified by their rudimentary character, such as the olfactory lobe (page 1152), apart from minor variations in details, the cortex of the greater part of the frontal, parietal, occipital, temporal and limbic lobes and of the insula closely corresponds in its structure. That of the motor (Rolandic) region, of the calcarine (visual) area of the occipital lobe, and of the hippocampus, dentate gyrus and adjacent part of the hippocampal gyrus, however, presents modifications which call for brief description.

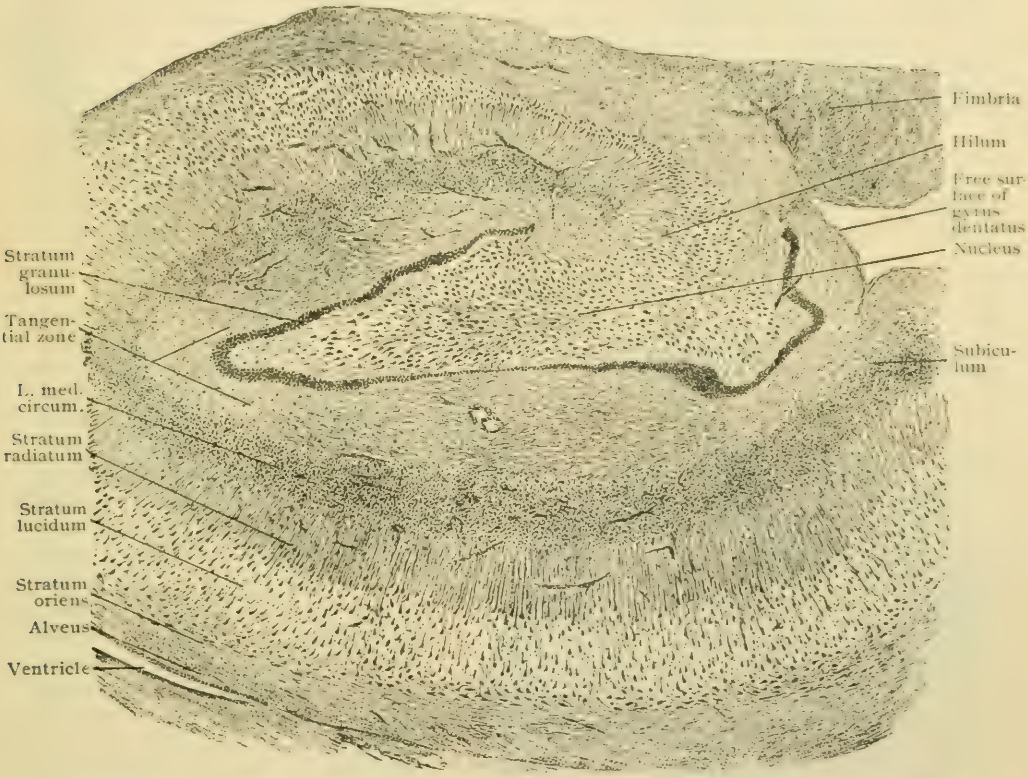
The **Rolandic cortex** of the precentral gyrus, particularly towards the upper margin of the hemisphere, of the paracentral lobule and of the adjoining part of the postcentral gyrus—the great cortical motor area of the hemisphere—is distinguished by the great breadth of the layer of large pyramidal cells, the unusual size of the last-named elements and the feeble development of the layer of polymorphic cells. The pyramidal cells collectively tend to larger size as the upper end of the precentral convolution is approached and, in addition, cells of extraordinary dimensions appear. These elements, known as the **giant pyramidal cells** of Betz, reach their maximum size within the paracentral lobule, where some attain a breadth of .065 mm. or almost double that of the pyramidal elements in other regions. The giant cells are further distinguished by their robust and rounded form, their distribution in small groups of from three to five in the deeper layers of the cortex, and the exceptional thickness of their axones.

The **occipital cortex** in the vicinity of the calcarine fissure (Fig. 1013) is distinguished even macroscopically by the clearness of the outer stripe of Baillarger, here called the *stripe of Gennari* or of *Vicq d' Azyr*. The stratum zonale is somewhat smaller than usual, but is exceptionally rich in tangential fibres and fusiform cells. The more superficially placed elements of the second stratum are spindle form rather than pyramidal and give off two

dendritic processes, one passing outward and the other toward the subjacent third layer, on entering which it divides and gives off the axone. At about the junction between the layer of small and large pyramidal cells, the stripe of Gennari is produced by a close felt-work of medullated fibres, beneath which the pyramidal cells very gradually increase in size. In the deepest part of the third and adjacent part of the fourth layer, pyramidal cells of unusually large dimensions occur singly or in small groups. The layer of polymorphic cells is well represented.

The **cortex of the hippocampus** and of the **gyrus dentatus** is a prolongation of that of the gyrus hippocampi, modified by the peculiar folding which here occurs. Reference to Fig. 992 will recall the relations of these gyri as seen on the mesial surface, namely, that at the bottom of the deep groove (the hippocampal fissure) above the hippocampal convolution lies the corrugated free surface of the dentate gyrus and above this the rounded mesial border of the hippocampus. Viewed in cross-section (Fig. 1018), the cortex of the hippocampal convolution is seen to bend laterally and pass into that of the hippocampus, which arches upward, mesially and

FIG. 1019.



Part of frontal section across left hippocampus and gyrus dentatus, showing arrangement of cell-layers. × 15.

then, turning sharply laterally, blends with the dentate gyrus, which recurves mesially to reach the free surface of the hemisphere and fill the recess between the hippocampal gyrus and the under surface of the hippocampus. The cortex of the hippocampus, therefore, is folded upon itself somewhat like the curve of an interrogation mark. On approaching its upper convexity, the cortex of the hippocampal convolution, here called the *subiculum*, becomes modified by the excessive but unequal thickening of the tangential fibre-layer of its stratum zonale and the irregularity of its layer of small pyramidal cells, the large pyramidal cells at the same time becoming the sole representatives of the third stratum. The layer of *tangential fibres*, somewhat thinned, passes onto the hippocampus which it follows throughout and comes, therefore, into apposition with the corresponding tangential zone of the dentate gyrus. The two fibre-layers are so blended that a differentiation between the two is impracticable. Beneath (1) the *layer of tangential fibres* lies a second stratum of medullated fibres, (2) the *lamina medullaris circumvoluta*, which is probably an intracortical association tract limited to the hippocampus. The zone succeeding the medullary lamina is penetrated by innumerable long dendritic processes of the large pyramidal cells and in consequence presents a radial striation, the layer

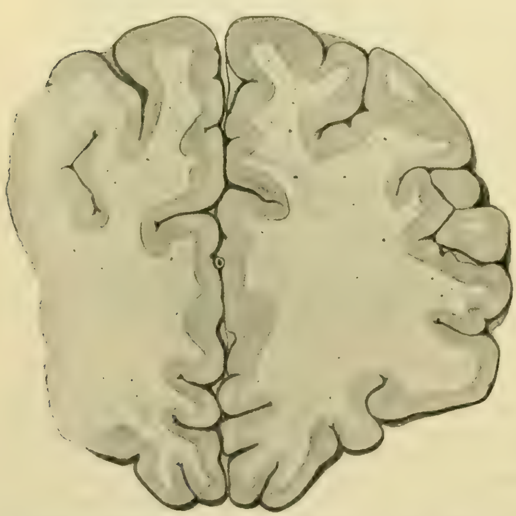
being appropriately termed (3) the *stratum radiatum.* Following this comes (4) the *layer of pyramidal cells.* These are uniformly of large size and closely packed within a clear ground-work which confers a light appearance upon the winding lamella, which is therefore sometimes known as the *stratum lucidum.* Beneath the pyramidal cells lies a layer of fibres, (5) the *stratum oriens,* which pass to and from the hippocampus ; among these fibres are embedded spindle cells, as well as peculiar association cells (Cajal) possessing richly branched axones which ramify among the pyramidal cells which they probably serve to link together. The axones of the pyramidal cells are directed chiefly towards the centre of the gyrus where, next the descending horn of the lateral ventricle, they form a conspicuous layer of fibres called (6) the *alveus.* It is this sheet, covered by (7) the *ventricular ependyma,* in connection with the stratum oriens, which confers the white color to the hippocampus, as seen within the ventricle. On reaching the recurved end of the hippocampus, the layer of pyramidal cells of the latter is not continuous with that of the dentate gyrus, but ends irregularly and is enclosed by the arched dentate cell-layer.

The **cortex of the gyrus dentatus** is highly modified and less in accord with the typical structure of the cortical substance than that of the hippocampus. The outer surface where buried in the concavity of the hippocampal arch lies in contact with the similar surface of the hippocampus, hence the peripheral layers of the two gyri are opposed. Within the gyrus dentatus may be recognized (1) the *stratum zonale,* relatively narrow and meagre in fibres. The surface of the gyrus is paralleled by a narrow layer of small and densely packed cells, (2) the *stratum granulosum.* These almost, but not quite completely, surround the gyrus and, therefore, leave an interval, the *hilum,* through which the fibres gain and leave the deeper parts of the convolution. Within the area so circumscribed, known as (3) the *nucleus* of the gyrus, are found irregularly disposed elements, the representatives of the layer of large pyramidal cells. They are for the most part small in size and atypical in form. Their axones, together with the continuation of the stratum oriens, pass through the hilum, the dentate gyrus thereby forming connections with other parts, either of the hippocampus or of the fimbria.

The White Centre of the Hemisphere.

The extensive medullary substance enclosed by the cerebral cortex appears, above the level of the corpus callosum, as a grayish white tract (*centrum semiovale*) of seemingly homogeneous structure, its uniform character being broken at most by minute blood-vessels. At lower levels, where the intercortical area is encroached upon by the large collections of gray substance composing the corpus striatum and the thalamus, the white matter is most conspicuous immediately subjacent to the cortex. When examined with the microscope after suitable preparation, the apparently homogeneous subcortical tissue is resolved into an intricate maze of medullated nerve-fibres, supported by neuroglia, which run in various directions and are, therefore, cut in different planes. When analyzed as to their relations with the cortex, the components of the medullary substance of the hemisphere fall into three general groups: (1) the *association fibres,* (2) the *commissural fibres,* and (3) the *projection fibres.*

FIG. 1020.



Frontal section of brain passing through hemispheres in front of corpus callosum; core of white matter is everywhere enclosed by cortical gray matter.

The Association Fibres.—The association fibres link together different portions of the same hemisphere, many uniting adjacent areas whilst others connect parts widely separated. They are grouped, therefore, as *long* and *short association bundles.* With the exception of a narrow zone in the immediate vicinity of the upper end of the Rolandic fissure, the cerebral cortex at birth is unprovided with association fibres which have acquired their medullary coat and, therefore, are capable of functioning.

Within the early months after birth, however, the myelination of these, as well as of other tracts, progresses rapidly, although this process is not even moderately completed until after the lapse of several years. Indeed, there is sufficient evidence to believe that myelination of additional fibres continues so long as intellectual effort is progressive, the demands made by education and special mental exercise being met by a corresponding completion of additional association fibres.

Fig. 1021.

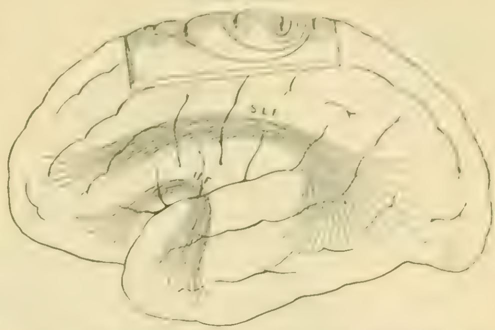


Diagram showing association fibres, lateral surface; part of left hemisphere removed to expose short fibres; long fibres are supposed to show through transparent hemisphere; *SLF*, superior longitudinal fasciculus; *UF*, uncinate fasciculus.

The **short association fibres** pass in great numbers from one convolution to the next, bending in U-like strands around the intervening fissure. Some of these loops are confined to the deeper layers of the gray matter and constitute the *intracortical association fibres*, whilst others occupy the adjacent white matter. These latter are known as the *subcortical association fibres*. In addition to the innumerable fibres which unite the adjoining convolutions (*fibræ propriæ*) and occupy the white matter immediately below the cortex, many connect gyri somewhat more widely separated, those limited to the convolutions of the same lobe constituting the *intralobar fibres* and lying at somewhat deeper levels within the medullary substance.

The **long association fibres** connect more or less remote portions of the cortex of the hemisphere, and, therefore, vary in length, but are sometimes of considerable extent. Numerous as such *interlobar* bundles undoubtedly are, only a few can be demonstrated with certainty. Among the most definite of these are: (1) the *uncinate fasciculus*, (2) the *cingulum*, (3) the *superior longitudinal fasciculus*, and (4) the *inferior longitudinal fasciculus*.

The **uncinate fasciculus** arises from the convolutions of the orbital surface of the frontal lobe, arches over the stem of the Sylvian fissure, close to the ventral border of the insula, and ends in the cortex of the anterior part of the temporal lobe.

The **cingulum** is a long arched tract lying within the limbic lobe. It begins in front in the vicinity of the anterior perforated space, arches around the anterior end of the corpus callosum, follows the upper surface of this structure, lodged within the callosal gyrus, and, curving around the splenium, descends within the hippocampal gyrus to end in the fore-part of the temporal lobe and perhaps also in the uncus. The cingulum is not composed of fibres which extend its entire length, but is made up of a number of shorter tracts, as shown by its incomplete degeneration after section of the fasciculus.

Fig. 1022.

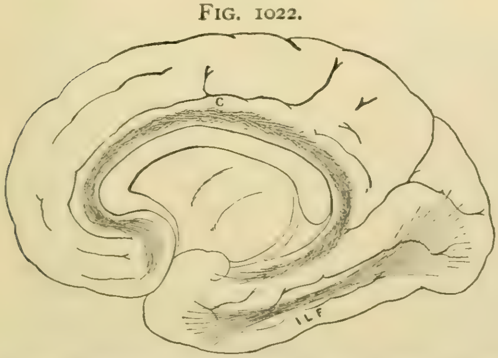


Diagram showing association fibres, mesial surface; fibres are supposed to show through transparent hemisphere.

The **superior longitudinal fasciculus**, also called the *fasciculus arcuatus*, passes from the frontal and parietal opercula, over the region of the insula, to the inferior parietal convolution, the occipital lobe and the superior and middle temporal convolutions. It is composed of a number of short bundles which proceed from the frontal lobe partly in the sagittal direction towards the occipital lobe, and partly in curves into the temporal lobe.

The **inferior longitudinal fasciculus** is a well-marked bundle which extends from the tip of the occipital lobe and the cuneus, along the outer side of the optic

radiation and the posterior and inferior horns of the lateral ventricle to the fore-part of the temporal lobe. It is probably an important path by which visual impressions are transmitted to other parts of the cortex (Dejerine).

Among the additional association tracts which have been described may be mentioned :

The **fasciculus occipitalis perpendicularis**, which extends from the upper part of the occipital lobe and the upper part of the inferior parietal convolution to the occipito-temporal convolution.

The **fasciculus fronto-occipitalis**, which courses sagittally and lies in intimate relation with the lateral ventricle and the caudate nucleus, and to the mesial side of the corona radiata.

The **fasciculus temporo-parietalis**, which unites the temporal convolutions with the cortex of the parietal region.

The **fasciculus fronto-parietalis**, which runs between the base of the lenticular nucleus and the claustrum and connects the frontal and parietal cortex.

The **fasciculus lobi lingualis**, which is a bundle passing from the ventral boundary of the calcarine fissure to the occipital cortex of the lateral surface of the hemisphere.

The Commissural Fibres.—Under this heading are included the fibres which cross the mid-line and connect the cortex of one hemisphere with that of the other, the regions so united being by no means necessarily identical on the two sides. Such discrepancy is accounted for, at least in part, by the frequent introduction of an association neurone in the commissural circuit, the impulse carried from one hemisphere to the other being thus transferred to another region of the cortex, from which there arises the return commissural fibre. Preparatory to crossing the median plane, the fibres are collected into compact masses which form three definite bridges or commissures : (1) the *corpus callosum*, (2) the *anterior commissure* and (3) the *hippocampal commissure*.

FIG. 1023.

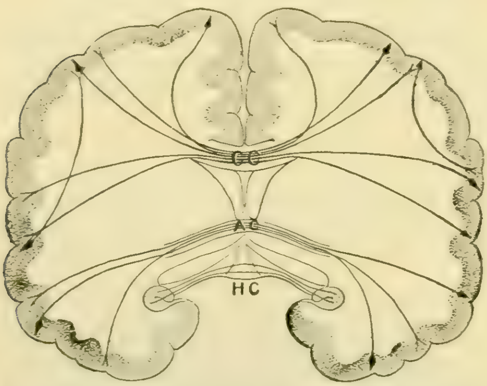


Diagram showing commissural fibres passing between cerebral hemispheres by way of corpus callosum (*CC*) anterior commissure (*AC*), and hippocampal commissure (*HC*).

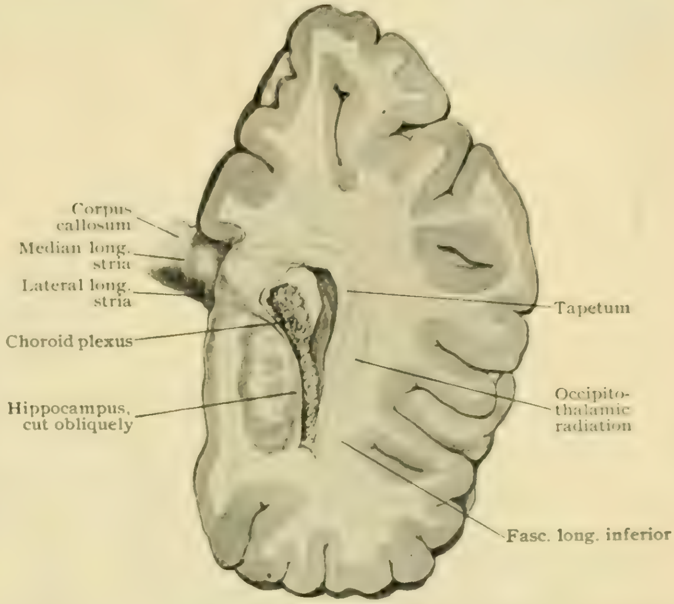
The fibre-system of the **corpus callosum**, the chief commissure of the pallium, is so extensive that it includes connecting strands from all parts of the cortex of the hemispheres with the exception of the front and under part of the temporal lobes and the two rhinencephala, which, on account of their isolated position, are provided with special bonds of union. The callosal fibres stream out in all directions, constituting the *radiation of the corpus callosum* (**radiatio corporis callosi**), of which an anterior, a middle and a posterior portion are recognized. The anterior division, the *pars frontalis*, comprises the fibres which cross in the genu and, as the forceps minor, pass to the frontal pole. The fibres constituting the middle portion, the *pars parietalis*, traverse the body of the corpus callosum and continue outward to the hind-part of the frontal and the parietal and temporal lobes. The posterior portion includes the fibres which form the splenium and the adjoining segment of the body of the corpus callosum. These course outward, downward and backward and as the *pars temporalis* and the *pars occipitalis* reach respectively the hind-part of the temporal and the occipital lobes. The fibres destined for the latter region lie within the splenium, from which, as a condensed bundle, the forceps major, they arch backward along the inner wall of the posterior horn of the lateral ventricle (page 1158) into the occipital cortex.

The fibres composing the corpus callosum probably all terminate in arborizations within the cortex of one or the other of the hemispheres. Their source in the opposite hemisphere, however, is by no means always the same, since they may arise: (1) as the axones of the pyramidal or of the polymorphic cells; (2) as the collaterals of association fibres; or (3) as collaterals of projection fibres, in the last two cases being, therefore, of the nature of association-fibres rather than of

strictly commissural ones. Indeed, with the more exact and extended study of the corpus callosum, it becomes more and more evident that the composition and relations of this great bridge are very intricate and complex, and that it receives contributions from a much larger number of and more diverse sources than was formerly recognized.

The observations of E. A. Spitzka upon the size and sagittal area of the corpus callosum have conferred additional interest upon this structure as a possible index as to intellectual development. The examination of a series of brains which included some from men of acknowledged intellectual superiority, demonstrated a corpus callosum of unusual area as a constant feature in the brains of the more highly endowed individuals. And, further, that the size of the corpus callosum bore a direct relation to the character of intellectual superiority which the individual was known to possess, the largest commissure being found in the brain of a man whose intellectual greatness implied the exercise of association paths to an unusual degree. The later conclusions of Bean, however, seriously question (consult page 1197) the constancy of the relations above suggested.

Fig. 1024.



Frontal section of right hemisphere, passing just behind splenium of corpus callosum ; inferior horn of lateral ventricle is cut obliquely.

The **anterior commissure** consists of a compact cord-like strand, slightly compressed from before backward and therefore oval in section (Fig. 996), which connects the anterior ends of the temporal lobes, as well as the olfactory bulbs. As it crosses the mid-line, the commissure is placed immediately in front of the downward arching anterior pillars of the fornix, in the interval between which it appears as a white transverse ridge on the narrow anterior wall of the third ventricle (Fig. 979). Its posterior surface is covered with the ventricular ependyma, whilst in front it is in intimate relation with the lamina cinerea (page 1131). Laterally it arches backward and downward, the entire commissure forming a Ω-shaped tract, with the convexity presenting forward, whose ends broaden as they sweep backward into the temporal lobes (Fig. 968). In addition to uniting the fore-parts of the last-named lobes, the anterior commissure connects the olfactory bulbs and consists, therefore, of a temporal and an olfactory part.

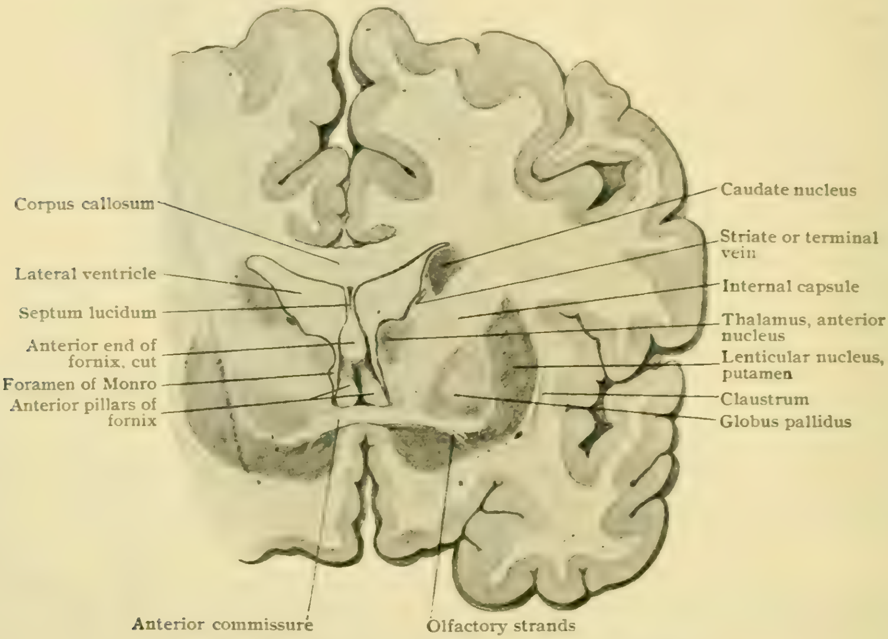
The *olfactory part* is much the smaller and appears as a delicate fasciculus which curves downward and forward to enter the olfactory tract. Its fibres include: (1) those which arise in one olfactory lobe and pass to that of the opposite side; (2) those which connect the olfactory lobe with the cortex of the opposite hippocampal convolution; (3) those which extend from the olfactory lobe through the commissure and, joining the tænia semicircularis, proceed with this strand along the roof of the inferior horn of the lateral ventricle to end in the amygdaloid nucleus (page 1172).

The *temporal part* includes the greater portion of the commissure. After passing almost horizontally outward beneath the lenticular nucleus (Fig. 1025) as far as the mesial borders of the putamen, it turns backward and continues its course beneath the lenticular nucleus, where it appears in frontal sections as a transversely

cut oval bundle until, farther backward, it bends abruptly downward to disappear in the white matter of the temporal lobe, to the outer side of the inferior horn of the lateral ventricle, preparatory to ending in the cortex.

The fundamental and archaic character of the rhinencephalon, this division of the hemisphere appearing in animals in which the pallium is only feebly developed, early led to the establishment of a special connection between the olfactory lobes of the two sides. When to this necessity was added that of linking together the fore-parts of the temporal lobes, which are to a considerable degree isolated, the establishment of a commissure supplementary to the corpus callosum was effected.

FIG. 1025.



Frontal section of brain passing through anterior commissure.

The **hippocampal commissure** connects the two hippocampi by means of fibres which cross in the psalterium (page 1158), in addition, some fibres thus undergoing decussation join the longitudinal strands of the fornix and proceed towards the thalamus.

The Projection Fibres. — These fibres connect the cortex of the cerebral hemisphere with the lower lying parts of the brain — the thalamus, the corpus striatum, the tegmental region, the pons and the medulla — and the spinal cord. Proceeding, as they do, from all parts of the extended cortical area towards nuclei grouped within the compass of a relatively small space, the fibres, for the most part, at first curve toward their objective points and collectively form the extensive converging tract known as the **corona radiata.** The greater number of the components of the latter pursue a direct path to the lower levels and take part, therefore, in the formation of the compact internal capsule. The projection fibres are by no means uniformly numerous in all parts of the cortex, relatively few issuing from the frontal, parietal and infero-lateral part of the temporal regions—areas which, according to Flechsig, are particularly significant as association centres. Furthermore, the olfactory cortex does not contribute to the corona radiata, its own special projection fibres being represented by the cortico-mammillary tract within the fornix (page 1159). The projection fibres are not exclusively corticifugal tracts, since the connections of the thalamus are of a double nature, numerous corticipetal paths passing from this great sensory nucleus to the cortex of the hemisphere. The projection fibres may

be conveniently considered under two groups, the *short* and the *long tracts*, according to the position of the nuclei with which they are associated.

The **short projection tracts** include the following: 1. The *cortico-thalamic tracts*, the fibres of which pass from all parts of the cortex of the hemisphere to the thalamus. The components of these tracts are: (*a*) fibres passing from the cortex of the frontal lobe to the anterior extremity of the thalamus; (*b*) fibres passing from the cortex of the Rolandic region and the adjoining part of the parietal lobe to the lateral and mesial nuclei of the thalamus; (*c*) fibres passing from the occipito-temporal lobe to the medio-ventral part of the thalamus; and (*d*) fibres passing from the posterior part of the parietal and from the occipital lobe to the pulvinar.

Associated with the foregoing corticifugal paths are the *thalamo-cortical tracts* which, coursing in the opposite direction (corticipetally), proceed by way of the stalks or peduncles of the thalamus (page 1122) to all parts of the cortical sheet of gray matter investing the cerebral hemisphere. The thalamo-cortical tracts (Fig. 969), are the continuations (by means of the thalamic neurones) of the afferent paths conveying impulses from the spinal cord and the brain-stem and from the cerebellum to the great sensory internode, the thalamus. These include, on the one hand, chiefly the *median fillet*, the *spino-thalamic tract* and, perhaps, a part of *Gowers' tract*, by which paths the sensory impulses collected by the spinal and the cranial nerves are transmitted to the thalamus; and, on the other hand, the *cerebello-rubro-thalamic tracts*, by which the cerebellum is linked with the thalamus by way of the superior cerebellar peduncle. The visual impulses carried by the fibres of the optic tract to the pulvinar are, in a similar manner, conveyed to the occipital cortex, along with those interrupted in the lateral geniculate and the superior quadrigeminal body, by the *optic radiation* of which the occipital stalk of the thalmus is a part.

FIG. 1026.

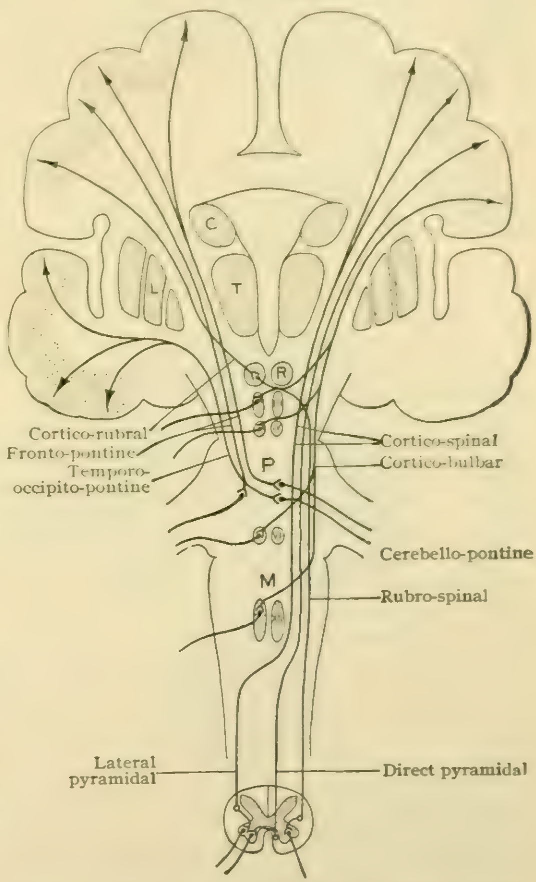


Diagram of long projection fibres; nuclei of cranial nerves are indicated by Roman numerals; *R*, red nucleus.

2. The *cortico-geniculate* and the *cortico-quadrigeminal tracts* are important constituents of the optic radiation. Their fibres extend from the occipital cortex to the primary optic centres and, as in the case of those going to the pulvinar, are accompanied within the radiation by corticipetal fibres passing from the small lateral geniculate body and the pulvinar.

3. The *auditory radiation* comprises both corticipetal and corticifugal fibres which, in proceeding outward, pass from the inferior quadrigeminal and the median geniculate body through the retrolenticular portion of the posterior limit of the internal capsule and beneath the lenticular nucleus to the auditory centre within the temporal lobe. This cortical centre includes the middle portion of the superior temporal convolution and, probably, the adjoining part of the temporal operculum.

4. The *cortico-rubral tract* constitutes a supplemental motor path. The exact location of its cortical origin is uncertain, but may be assumed, at least provisionally, to lie within the parietal lobe.

The **long projection tracts** embrace two important groups, the *cortico-pontine* and the *motor tracts*, the former contributing the first link in the chain connecting the cerebral and the cerebellar cortex, and the latter constituting the bond between the cortical gray matter of the hemisphere and the motor nuclei of the cranial and of the spinal nerves. The long projection fibres are important constituents of the internal capsule which they all traverse.

1. The *cortico-pontile tracts* include two chief subgroups, the *fronto-pontile* and the *temporo-occipito-pontile*, which below end around the cells of the pontile nucleus, whence the impulses are transmitted to the cerebellum by the ponto-cerebellar strands of the same and opposite sides.

a. The *fronto-pontile tract* arises from the cortex of the frontal lobe and, passing by way of the corona radiata, enters the hind-part of the anterior limb of the internal capsule. Descending into the crusta of the cerebral peduncle, in which it occupies the mesial fifth, the tract ends within the ventral part of the pons around the nerve-cells constituting the pontile nucleus.

b. The *temporo-occipito-pontile tract* proceeds from the cortex of the temporal and the occipital lobes through the hindermost segment of the posterior limb of the internal capsule. On reaching the cerebral peduncle, its position corresponds approximately with the lateral fifth of the crusta. It ends within the pons around the cells of the pontile nucleus in the same manner as does the last-described tract.

2. The **motor tracts** are composed of fibres which connect the cells within the cortical areas of the Rolandic region with the nuclei from which arise the root-fibres of the motor nerves. Since the latter take origin within the brain-stem as well as within the spinal cord, the motor tracts comprise two groups—the *cortico-bulbar* and the *cortico-spinal tracts*. The exact locations of the cortical areas controlling the various cell-groups giving origin to motor nerves are still far from being accurately known. Clinical and experimental studies have indicated with considerable certainty, however, that the cerebral cortex in the immediate vicinity of the Rolandic fissure, chiefly in the precentral convolution and paracentral lobule, and probably also in the adjacent parts of the superior and middle frontal gyri, is the most important seat of such motor centres. In a general way, the areas controlling the muscles of the lower limb lie highest and are situated in advance of and around the upper part of the Rolandic fissure. The conspicuous backward projection of the precentral gyrus (Fig. 984) corresponds to the arm-area, whilst the lower part of the same convolution contains the centres for the neck and face. (Consult also page 1212.)

a. The *cortico-bulbar tract* includes the fibres ending around the nuclei from which proceed the motor fibres of the cranial nerves. The fibres, therefore, arise from the pyramidal cells of the cortex of the lower part of the precentral gyrus and, for the eye muscles, of the posterior portion of the inferior frontal convolution (Mills). Proceeding by way of the corona radiata, the cortico-bulbar path occupies the segment of the internal capsule which forms the genu, being bounded in front by the fibres of the fronto-pontine tract and behind by those of the cortico-spinal tract. The exact location of the strands destined for the several nerves is known only for the facial and the hypoglossal, those for the last-named nerve occupying the most posterior part of the genu, whilst those for the facial lie just in advance of the fibres for the twelfth. Within the cerebral peduncle (Fig. 1012), the cortico-bulbar strand occupies the lateral part of the inner third of the crusta, the fibres destined for the third and fourth nerves soon turning dorsally and crossing the raphe to end, for the most part, in relation with the nuclei of the opposite side. The fibres for the lower lying nuclei continue through the crusta and enter the ventral part of the pons ; they then assume a median position and at appropriate levels bend dorsally and cross the mid-line to end in relation with the cells of their objective motor nuclei, some few fibres probably ending in the nuclei of the same side.

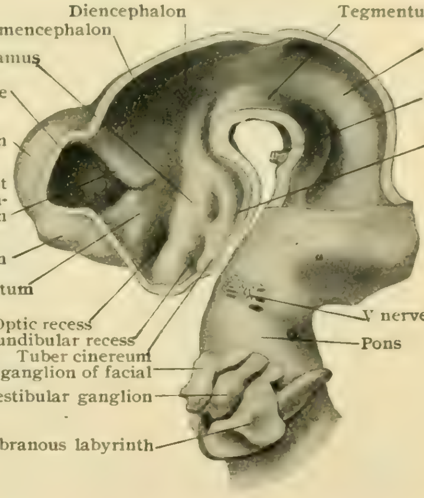
b. The *cortico-spinal* or the *pyramidal tracts* include the longest of all the projection fibres, which, as in the case of those passing to the nuclei of the sacral

nerves, may traverse the entire thickness of the brain and the length of the spinal cord. They arise from the pyramidal cells of the Rolandic cortex, follow the corona radiata into the internal capsule, within which they occupy approximately the front half of the posterior limb, those destined for the cervical nerves lying in advance of those for the trunk and leg nerves. Within the peduncle, the cortico-spinal tract appropriates approximately the middle third of the crusta, having the pontine paths to its outer side. The further course of these fibres leads through the ventral part of the pons and of the medulla, until near the lower limit of the last named division of the brain-stem, the greater part of the pyramidal strands take part in the motor decussation and thence descend within the lateral pyramidal tract to their appropriate levels where they end in relation with the radicular cells of the anterior horn (page 1043). The fibres which do not cross in the pyramidal decussation exchange their lateral position for a median one and continue within the cord as the direct pyramidal tract at the side of the median longitudinal fissure. Before gaining their final levels within the cord, these fibres also cross, by way of the anterior white commissure, to end around the root-cells of the opposite side.

Development of the Parts Derived from the Fore-Brain.

It has been pointed out in the general sketch of the development of the brain (page 1060), that the fore-brain very early undergoes subdivision into two secondary cerebral vesicles, the anterior of which is the *telencephalon*, or *end-brain*, and the posterior the *diencephalon*. Each of these secondary vesicles gives rise on each side to two general regions, an upper and a lower, which in the telencephalon are the *hemisphærium* and the *pars optica hypothalami* and in the diencephalon are respectively the *thalamencephalon* and the *pars mamillaris hypothalami*. These two parts of the hypothalamic region together constitute the *hypothalamus*, which includes the portion of the lateral wall of the fore-brain lying below the level of the foramen of Monro and corresponds to the ventral or basal lamina of the neural-tube (Fig. 914). This tract gives rise to the structures situated along the floor of the third ventricle — the mammillary bodies, the tuber cinereum, the infundibulum and the posterior lobe of the pituitary body, the optic chiasm and the optic tracts. The anterior wall and the roof of the fore-brain always remain thin. This is especially true of the roof, which, with the exception of its hindmost part where the posterior commissure is formed, does not lead to the development of nervous tissue but remains thin, being later represented by the attenuated epithelial layer which constitutes the morphological roof of the third ventricle. The anterior wall of the fore-brain is the thin median partition known as the *lamina terminalis*, which, whilst giving rise to the rudimentary sheets of gray matter found within the lamina cinerea and the septum lucidum, is to a large extent concerned in the production of the great commissure, the corpus callosum.

Fig. 1027.



Reconstruction of brain of human embryo of four and one-half weeks (10.2 mm.), inner surface of the fore-brain and mid-brain exposed by mesial section. (Exterior of same brain is shown in Fig. 1141.) × 12. Drawn from His model.

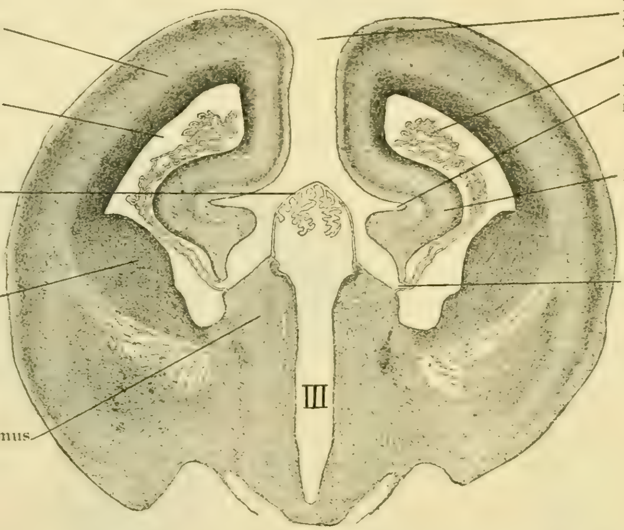
The *hemisphærium*, one on each side, comprises by far the greater portion of the end-brain and represents an enormous expansion of the dorsal or alar lamina of the neural tube. Very early it exhibits a differentiation into: (*a*) the *pallium*, (*b*) the *rhinencephalon* and (*c*) the *corpus striatum*.

The Pallium.—Of the three parts of the hemisphærium, in man the pallium soon becomes the most conspicuous, since from the walls of this rapidly expanding hemispherical pouch is derived the great sheet of cortical gray substance which invests the cerebral hemisphere. For a time enclosing a large cavity with thin walls, the pallium later becomes consolidated by the

intergrowth of the fibre-tracts (later the white matter), which arise partly from the young nerve-cells within its walls and partly from neuroblasts situated in other segments. An additional factor of moment in the production of the bulky cerebral hemisphere is the special mass of gray matter, the corpus striatum, which, with the increasing fibre-tracts, leads to the reduction and conversion of the cavity of the pallium to the irregular lateral ventricle. Its once wide communication (Fig. 1030) with the cavity of the fore-brain is retained as the proportionately narrow foramen of Monro. The pallium expands in all directions save directly downward, where increase concerns chiefly the rhinencephalon, but the lines of its growth are particularly backward and downward, in consequence of which, in addition to the production of a temporal and the distinctive occipital lobe, the other brain-segments become gradually covered over and deposed from their original superior position toward the basal surface of the brain. This process is already marked during the third month (Fig. 1031), by the end of which period the pallium covers the diencephalon. By the beginning of the fifth month the mid-brain is completely overlaid, and by the eighth month the entire upper surface of the cerebellum is covered.

Development of the Sulci and Gyri.—The modelling of the surface of the cerebral hemisphere begins towards the end of the fifth month of fœtal life, by which time the occipital lobe is well formed and the brain-case is separated from the cerebral surface by an intervening layer

FIG. 1028.



Frontal section of brain of rabbit embryo showing invagination of mesial wall of hemisphere along hippocampal and choroidal fissures; thin roof-plate of third ventricle stretches between thalami. × 13.

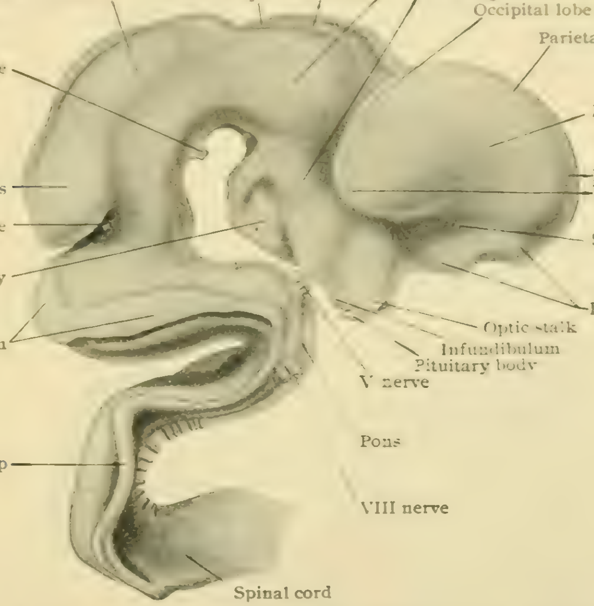
of yielding arachnoid tissue, which offers little opposition to the production of the convolutions which now follows. Preceding this period, the outer surface of the young hemisphere is quite smooth, with the exception of the crescentic Sylvian fossa (Fig. 982) which marks the position of the later insula. This depression has been described (page 1137) in connection with the production of the Sylvian fissure. The uncertain creases, the so-called "transitory fissures," sometimes seen on brains of a much earlier period are without morphological significance and are now usually regarded as artefacts (Ziehen, Hochstetter).

Long antedating the appearance of the fissures on the outer aspect of the pallium, the mesial surface of the latter is early marked by two grooves, the *choroidal* and the *hippocampal fissures*. The first of these (Fig. 1031) appears by the end of the fifth week as an invagination of the mesial wall of the pallium just above the position of the foramen of Monro. At first small, the groove is carried backward and downward by the expansion of the pallium until, finally, it is traceable along the inner wall of the inferior horn of the lateral ventricle as far as its lower limit. Entering by means of this invagination, the mesoblastic tissue forces before it the attenuated cerebral wall and expands into a voluminous mass, the *choroid body*, which on becoming supplied with blood-vessels, forms a vascular complex that for a time almost completely fills the early lateral ventricle. With the subsequent growth of the pallium backward and downward, the choroidal fissure and the contained vascular fringe are carried from the foramen of Monro over and around the thalamus into the inferior horn of the lateral

ventricle, where its remains are seen as the definite choroid plexus. The second furrow, the *hippocampal fissure*, appears shortly after and above the choroidal on the mesial surface of the pallium. Its primary position is marked by an invagination affecting the entire thickness of the cerebral wall (Fig. 1028), which, therefore, appears on the inner aspect of the wall of the pallium as an arched longitudinal ridge, the later hippocampus. At first open on the mesial surface, the fissure subsequently becomes almost entirely filled by the dentate gyrus and in the fully developed brain is scarcely seen.

The *central sulcus* or the *fissure of Rolando* is usually the first of the permanent furrows to appear on the outer surface of the hemisphere. As a rule, it is recognizable during the last week of the fifth month, although its appearance may be delayed until a month later (Cunningham). When laid down as two separate furrows, as it not infrequently is, the lateral one is the longer and usually the deeper. Subsequently the two parts become united into a continuous sulcus, although very rarely the primary condition may persist and the Rolandic fissure be interrupted by a superficial gyrus. During the fifth month, on the mesial surface of the hemisphere, also appear the *calcarine* and the *parieto-occipital fissure*. The first of these is often mapped out by two or even three separate parts, of which the front one is complete and, as the anterior limb of the calcarine fissure, produces the elevation known as the calcar avis. The

FIG. 1029.



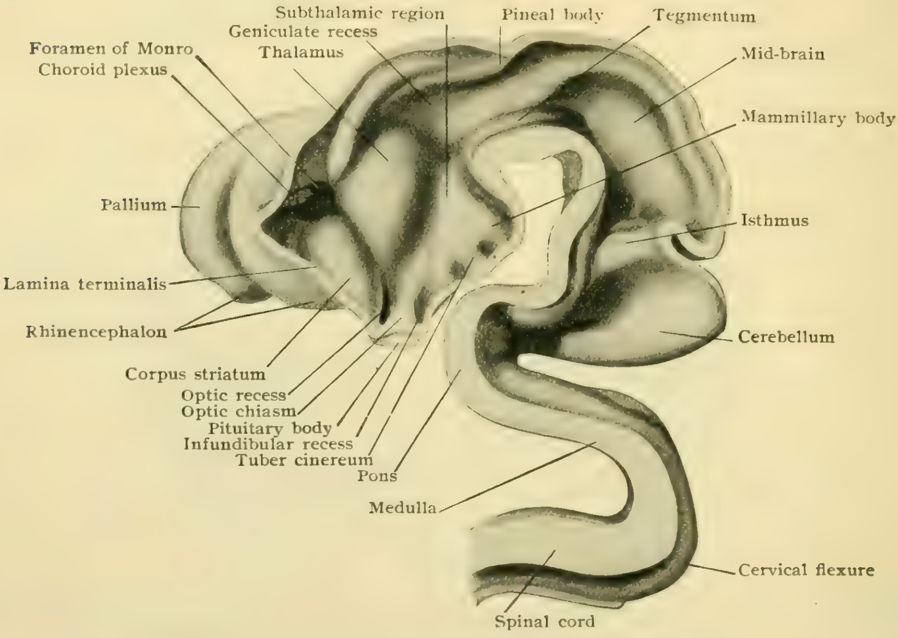
Reconstruction of brain of human embryo of five weeks (13.6 mm.); external lateral aspect. × 11. Drawn from His model.

other parts subsequently unite to form the posterior limb of the calcarine fissure. When first formed the parieto-occipital fissure is usually distinct from the calcarine, with which, however, it soon becomes confluent. Towards the end of the fifth month the *collateral fissure* appears on the inferior surface of the hemisphere. The *inferior* and the *superior precentral sulcus* may usually be distinguished, the lower slightly in advance of the upper, during the early weeks of the sixth month, and about the same time the *superior temporal* and the *olfactory sulcus*. The middle of the sixth month marks the appearance of the postcentral and occipital limbs of the *interparietal sulcus* and the first suggestion of the *orbital furrows* and the *calloso-marginal sulcus*, as well as the junction of the inferior frontal with the lower precentral sulcus. Towards the close of the same month are added the *superior frontal*, the *inferior temporal* and the *occipital sulci*. The seventh month witnesses the extension and deepening of the fissures already formed and the union into continuous sulci of parts which before were separate. During the succeeding month, the surface of the hemisphere and the brain-case once more come into intimate relation, from which it follows that the rounded elevations marking the convolutions can no longer unrestrictedly expand, but from now on must accommodate themselves in their growth to the inner surface of the cranium. In consequence of this limitation, the convolutions become less rounded and more closely packed, and the free surface of the hemisphere conforms with the interior of the cranium. Increased complexity in the details of the convolutions arises from the

development of secondary gyri and sulci, although the definite brain-pattern is not completed until long after birth.

Histogenesis of the Cerebral Cortex.—The changes in the walls of the brain-vesicles incident to the development of the nervous elements of the cerebral cortex correspond essentially with those occurring in the cord-segment of the neural tube (page 1049). The wall of the pallium early differentiates into three zones: an *inner layer*, at first crowded with closely packed and radially disposed proliferating cells; an *intermediate* or *mantle layer*, composed of more loosely and less regularly arranged cells; and a narrow *marginal layer*, in which nuclei are absent. The cells of the intermediate layer very soon are differentiated into two kinds, which, in recognition of their fate, are known as the *neuroblasts* and the *spongioblasts*. Although both varieties are derived from the indifferent primary elements composing the walls of the brain-tube, the spongioblasts are concerned in producing the sustentacular tissue, the neuroglia, whilst the neuroblasts give rise to the neurones. The derivatives of the spongioblasts become elongated into nucleated radial fibres, which by their numerous processes form a supporting syncytium that at the inner and outer borders of the brain-wall is condensed into the *internal* and the *external limiting membrane* respectively. The neuroblasts are soon distinguished by the outgrowth of a single and centrally directed process,

FIG. 1030.



Mesial surface of preceding reconstruction. Drawn from His model.

which later is continued as the axis-cylinder of a nerve-fibre. They are further distinguished by their peculiar affinity for stains, which deeply tinge the pointed ends of the cells from which the axones are prolonged. A second process later grows from the young neurone in the opposite direction, that is, towards the exterior of the brain, and becomes the peripherally directed apical dendrite. The latter stains slightly and gradually invades the marginal layer. After the appearance of the apical processes, the conversion of the neuroblasts into the characteristic pyramidal cortical cells follows, so that by the end of the eighth week these distinctive elements are recognized. The production of additional pyramidal cells is continued by the migration of neuroblasts from the nuclear layer. The subsequent formation of the subcortical white matter follows the invasion of the inner part of the intermediate layer by not only the axones of the pyramidal cells but by those of cells lying in more remote parts of the brain, ingrowth of fibres taking place particularly from the thalamus. The young nerve-fibres for a time are unprovided with medullary coats, the period at which myelination occurs marking the completion of the fibre as a path of conduction. The time at which the fibres composing the various tracts within the brain acquire a medullary coat varies greatly. In a general way, according to Flechsig, those constituting the corticipetal sensory paths first myelinate; then the projection-fibres from the sense-areas, and last of all the association strands, which link together the sense-areas and the association fields.

The Rhinencephalon.—The rhinencephalon, using the term as including the various parts of the hemisphere concerned with receiving and distributing the impulses of smell, comprises an anterior division, the *olfactory lobe*, and the posterior or *cortical division*. The olfactory lobe is suggested in embryos of the sixth week (Fig. 1029) by an elongated oval area, imperfectly defined from the under surface of the pallium by the rhinal furrow, and partially subdivided by a faint transverse groove into a fore and a hind part. From the anterior division are developed the olfactory bulb, tract, tubercle and striæ and the parolfactory area; from the posterior, the anterior perforated space and the subcallosal gyrus. Although always relatively rudimentary in man, the olfactory lobe at first contains a cavity prolonged from the lateral ventricle, and in this respect resembles the corresponding but much larger olfactory lobe of the osmatic animals which remains hollow. In the human brain, however, this cavity, the *olfactory ventricle*, is only transient and later entirely disappears, its former position being indicated in the adult structure by the central area of modified neurogliar tissue (page 1152).

The *posterior* or *cortical division* includes the uncus, the hippocampus, the gyrus dentatus with the associated supracallosal gray matter and nerve-strands. The original position of the olfactory cortical area in the early human hemisphere corresponds with the permanent location of the similar region in animals in which the expansion of the pallium never leads to the formation of a well-marked occipito-temporal lobe. The early appearance of the primary hippocampal and choroidal fissures defines an intervening tract upon the mesial surface of the pallium. This is the *primary gyrus dentatus* and, with the hippocampal invagination, represents the earliest differentiation of the olfactory cortical area. Connection between the latter and the region of the mammillary body is subsequently established by the advent of the cortico-mammillary strand, later the chief part of the anterior column of the fornix. In consequence of the migration of the hippocampus and the dentate gyrus incident to the formation of the occipito-temporal regions of the hemisphere, the chief parts of the olfactory cortex are carried downward and forward into the inferior horn of the lateral ventricle. Along with the displaced cortical area necessarily follows the strand connecting it with the mammillary region, hence the prolongation of the fornix, by means of its posterior pillar and the fimbria, into the descending horn of the lateral ventricle. Although the major part of the olfactory cortex thus comes to occupy the infero-mesial temporal region, a small portion retains its superior connection and later, when the corpus callosum appears, becomes the greatly attenuated sheet of gray matter which, with its reduced fibre-strands, overlies the upper surface of the bridge as the atrophic supracallosal gyrus.

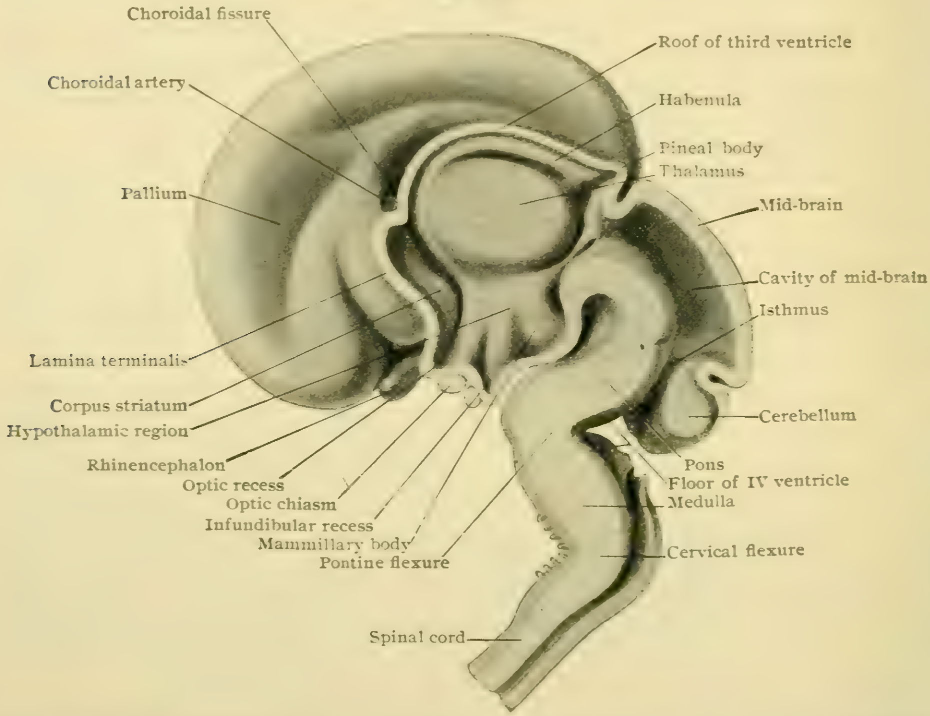
The Corpus Striatum.—The anlage of the corpus striatum, the fundamental ganglion of the end-brain, is recognizable very early, and in brains of the fourth week appears as a triangular elevation between the cavity of the pallium and the optic recess (Fig. 912, *B*). Somewhat later (Fig. 1030), this elevation, produced by a local thickening of the brain-wall, is seen projecting from the infero-lateral wall of the pallium just in advance of the large foramen of Monro. On the external surface of the pallium this thickening corresponds with the floor of the Sylvian fossa (Fig. 982), and it is this close association between the corpus striatum and this area, which fails to keep pace in its growth with the surrounding parts of the hemisphere, that leads to its envelopment by the opercula and the permanent covering of the insula. The subsequent partial separation of the corpus striatum into its two segments, the caudate and the lenticular nucleus, as well as the isolation of a thin peripheral cortical plate, the claustrum, is effected by the subsequent ingrowth of the strands of fibres which later become the internal and external capsule.

The Diencephalon.—The posterior division of the fore-brain, the diencephalon, very early (Fig. 1027) exhibits differentiation into an upper and a lower part. The former is the *thalamencephalon* and the latter the *pars mammillaris hypothalami*, which correspond to expansions from the dorsal and ventral laminæ of the brain-tube respectively. The thalamencephalon is much the larger and gives rise to the bulky mass of the *thalamus* from its anterior two-thirds and to the epithalamus and the metathalamus from its posterior third. The *epithalamus* is prolonged backward and from its upper surface an evagination occurs, the walls of which later thicken and become the pineal body. Subsequent ingrowth of fibres across the bottom of a transverse groove behind and below the pineal evagination leads to the establishment of the posterior commissure, whilst thickening of the part of the epithalamus lying in front of the pineal recess gives rise to the habenular region. The *metathalamus* appears at first as a triangular area lying behind and to the outer side of the thalamus, with which it is closely connected. It early presents two slight external elevations which become the lateral and median geniculate bodies. The diencephalic division of the *hypothalamus* early shows a differentiation into a series of elevations and furrows, the thickened areas becoming the mammillary body and the subthalamic region.

The *roof of the diencephalon* is thin from the first and remains so. In front it is directly continuous with the correspondingly attenuated plate which connects the hemispheres and, arching over the foramen of Monro, joins the lamina terminalis that closes the cavity of the

fore-brain, the later third ventricle, and contributes the anterior wall of this space. Attention has been called to the invagination of the mesial pallial wall along the primary choroidal fissure immediately above the line of attachment of the roof-plate to the hemisphere (Fig. 1031). The latter is connected with its fellow of the opposite side by means of this thin lamina, upon whose upper surface the mesoblastic sheet of the young pia is spread. On each side the same sheet is prolonged through the choroidal fissure into the cavity within the pallium, where it forms an extensive vascular mass, the *choroid body*, which, for a time, fills the greater part of the hemispherical space, but from actual entrance into which it is now, as well as subsequently, separated by the attenuated invaginated wall of the pallium. This displaced wall, with the enclosed pial tissue, afterward becomes the choroid plexus of the lateral ventricle and is carried downward along the mesial surface of the inferior horn with the formation of the temporal lobe. Where the mesoblastic sheet overlies the roof of the fore-brain it becomes the velum interpositum, which, it is evident, is continuous on each side with the choroid plexus. Since the choroidal fissure begins in front at a point which later overlies the foramen of Monro and, further, since the choroid plexuses of the two sides are connected by

FIG. 1031.



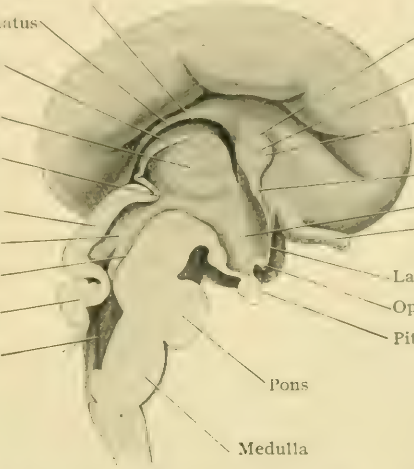
Reconstruction of brain of human fœtus of 3 months (50 mm.); mesial surface. × 4½. Drawn from His model.

the intervening velum interpositum, it follows that the plexuses converge towards and meet over the foramina—a relation which they retain in the adult brain. The backward expansion of the hemispheres is accompanied by a corresponding backward prolongation of the young pia mater covering the roof of the diencephalon, later the third ventricle. After the corpus callosum and the fornix have been superimposed, the impression is given from the relation of the structures, as seen in the completed brain, that the pia has gained its position over the roof of the third ventricle by growing forward beneath the splenium and fornix. That such, however, is not the case is evident from the developmental history of the velum interpositum. The secondary invagination of the brain-roof on each side along the median line by the vascular tissue of the pia accounts for the production of the choroid plexus of the third ventricle.

The Cerebral Commissures.—The primary simplicity of the connections between the hemispheres is disturbed by the formation of the commissures, which become necessary in order to link together the increasing sheets of cortical gray matter. The development of these commissures, the corpus callosum and the anterior commissure, as well as of the septum lucidum, are intimately associated with changes which affect the lamina terminalis.

About the fourth month, the last-named structure, which until this time is of uniform width, exhibits a local thickening in its upper part just in front of the foramen of Monro and in advance of the front-end of the choroid fissure. This thickening of the lamina terminalis, at first oval in section, soon becomes pear-shaped with the point directed downward (Fig. 1032). The point enlarges and, after its later invasion by an ingrowth of transverse fibres, forms the anterior commissure. The upper part of the thickened area expands in the sagittal direction and is traversed by fibres which pass from one hemisphere to the other. It thus becomes the corpus callosum. This structure soon assumes an elongated and slightly arched form, but does not appropriate the entire enlarged upper part of the originally pyriform area. The antero-inferior portion, covered above by the corpus callosum, remains thin and is converted into the septum lucidum. The fibres of the fornix appear early along the choroidal margin of the hippocampus, forming a bundle of increasing size as it extends forward over the foramen of Monro. The development of the corpus callosum is closely connected with that of the fornix commissure (Streeter). The septum lucidum is at first solid although thin; subsequently it is partially separated into two lamellæ by a narrow cleft, the so-called fifth ventricle, which is completely closed, is devoid of an ependymal lining, and, therefore, is no part of

FIG. 1032.



Mesial surface of left half of human fœtus of fourth month. × 2. (*Marchand.*)

the system of true ventricular spaces. Concerning the manner and reason of its formation opinions differ. The older view, that the space represents an isolated portion of the longitudinal fissure cut off during the development of the corpus callosum, is sustained neither by its history nor by the adult condition of the septum lucidum in many animals in which the partition is solid and no space exits. Goldstein,[1] however, accepts this view, while Marchand,[2] His and others, regard the splitting as secondary. In consequence of the growth, increasing bulk and backward extension of the corpus callosum and the fusion of the fornix along its under surface, the primary upper part of the hippocampus, which extends well forward along the mesial surface of the hemisphere, entirely disappears, its furrow, the hippocampal fissure, being later represented by the callosal sulcus, whilst the corresponding portion of the gyrus dentatus is reduced to the atrophic sheet of gray matter and the longitudinal striæ found upon the upper surface of the corpus callosum.

MEASUREMENTS OF THE BRAIN.

The brain fits within the cranial case so accurately that its form is modified by the general shape of the skull, being relatively long and ellipsoidal in dolichocephalic subjects and shorter and more spherical in brachycephalic ones. The usual length of the brain, measured from the frontal to the occipital pole, is from 160–170 mm. (6½ in.) in male subjects and from 150–160 mm. (6 in.) in female. Its greatest transverse diameter is about 140 mm. (5½ in.) for both sexes and its greatest verti-

[1] Archiv f. Anatom. u. Entwickelung., 1903.
[2] Archiv f. mikros. Anatom., Bd. xxxvii., 1891.

cal dimension through the hemisphere is about 125 mm. (5 in.). The female brain is commonly somewhat shorter than that of the male, and, therefore, relatively broader and deeper.

The **weight** of the brain has been the subject of repeated investigation with results that fairly agree. The conclusions of Handmann[1], based on recent examinations of 1014 brains (546 male and 468 female) from persons ranging in age from fifteen to eighty-nine years, are of interest since they confirm in the main the results obtained from previous observations. The average weight of the adult brain (from 15–49 years), without the dura but surrounded by the arachnoid and pia, is 1370 grams (48.6 oz.) for men and 1250 grams (44.4 oz.) for women. The weight of these membranes, including the enclosed arachnoid fluid, has been estimated at 56 gm. and 49 gm. in male and female brains respectively (Broca). The brain usually attains its maximum weight about the eighteenth year, perhaps somewhat earlier in women, no increase taking place after the twentieth year. Subsequent to the sixtieth year in both sexes a progressive diminution occurs, by the age of eighty the brain having lost approximately one-fifteenth of its entire weight (Boyd). Including the brains of individuals between fifty and eighty-nine years in his series, Handmann found the average weight to be 1355 gm. (47.8 oz.) for men and 1223 gm. (40.3 oz.) for women. Approximately 81.5 per cent. of adult male brains have a weight between 1200 and 1500 gm.; 8.8 per cent. one of from 950–1200 gm.; whilst 20.3 per cent. possess a weight over 1450 gm. Correspondingly, about 84 per cent. of female brains weigh between 1100–1400 gm.; 44 per cent. between 1200–1350 gm.; and 46 per cent. below 1200 gm. The average weight of the brain of the new-born male child is 400 gm. (14 oz.) and that of the female one is 380 gm. (13.4 oz.). During the early years of childhood the brain rapidly becomes heavier, its weight being doubled by the end of the first year and trebled by the completion of the sixth year. At first the increase affects the brain equally in both sexes; later the young female brain fails to keep pace in its growth with the male one, the differences becoming progressively more marked.

Whilst the *brain-weight and stature* stand in direct ratio in the new-born and in children up to 75 cm. in length, irrespective of age and sex, after attaining such stature the relation is irregular and uncertain. Likewise in the adult, Handmann found no constant ratio between the stature and the brain-weight, although in general a lower average weight of the brain is found in short individuals than in those of moderate and of large height. The *relative brain-weight*, as expressed in the ratio between each centimeter of height and the brain-mass, Handmann found to be 8.3 gm. for each centimeter of height in men and 7.9 gm. in women, a slightly higher proportion in favor of the male subject being thus observed. The average ratio of the weight of the adult brain to that of the entire body is approximately 1:50 (Obersteiner). In the new-born child this ratio is much greater, being, as determined by Mies, 1:5.9. Of the entire weight of the brain, the hemispheres contribute 78.5 per cent., the brain-stem 11 per cent., and the cerebellum 10.5 per cent., no material difference being observed in the two sexes (Meynert).

The extent of the *superficial surface* of the cortex has been determined, at least approximately, by Wagner, who by completely covering the convolutions with gold leaf concluded that the large brain of the mathematician Gauss (1492 gm.) presented an aggregate area of 221,000 sq. mm., or not quite one-half square meter. Of this entire area about twice as much lay along the sides and bottoms of the fissures, therefore sunken, as upon the exposed surface. The estimate of the same observer concerning the brain of a workman placed the area at 187,672 sq. mm.

The significance of brain-weight as an index of intellectual capacity has long excited interest. Accumulating data prove beyond question that, as applied to individuals, the weight of the brain is an untrustworthy index of relative intelligence. For whilst in a number of conspicuous examples the weight of the brains of men of acknowledged intellectual superiority has been markedly above the average, it is equally true that some of the heaviest brains recorded have been those of persons of ordinary, and indeed in some cases of even decidedly inferior, intelligence. Further, the brains of not a few men of remarkable achievement in the fields of Science,

[1] Archiv f. Anat. u. Entwickelung., 1906.

of Letters and of Art have possessed a weight little above, or sometimes even below, the average. In this connection it must be remembered that it is not improbable that the cortical cells of different brains vary in their capacity for activity and in their power of retaining impressions; that, in short, differences of quality exist. Further, that notwithstanding the possible low general weight of a brain, the amount of the cortical gray matter, especially of certain regions concerned in some particular phase of mental activity, may exist in unusual abundance. Moreover, it is probable, from the investigations of Kaes[1], that actual increase of the functioning association fibres takes place in response to the stimulus induced by excessive exercise of certain parts of the cortex. It is evident, therefore, that as applied to the individual, brain-weight alone affords little dependable information as to intellectual power, and that brains which, judged from their weight, apparently have been ordinary, may have been exceptional in the amount of cortical gray matter and, perhaps, in the unusual capacity of their neurones.

Considered, however, in relation to great groups, as to peoples or to races, brain-weight has been found to correspond to the general plane of intelligence and culture. In this connection the observations of Bean[2] are suggestive. He found the average brain-weight of the male negro to be 1292 gm., with extremes of 1010 gm. and 1560 gm.; that of the male Caucasian 1341 gm., with extremes of 1040 gm. and 1555 gm. Notwithstanding the relatively low class of the white subjects examined, the average weight of their brains was greater than that of the high-class negroes. Bean concludes that the smaller size of the negro brain is primarily in the frontal lobe, and, therefore, that the anterior association centre is relatively and absolutely smaller.

The observations of E. A. Spitzka[3] concerning the area of the corpus callosum in median sagittal section, call attention to the unusual size of this commissure in the brains of men of conspicuous intellectual power. Moreover, in the particular group of brains thus examined variations in the details of the callosa strikingly suggested well-known differences in the mental traits of the persons during life. The validity of the area of the callosum as a trustworthy index as to intellectual capacity has been seriously affected by the fact, illustrated by Retzius and by Bean, that callosa of uncommon size usually belong to brains of high weight, and that not infrequently such brains are from individuals of ordinary or even of low intelligence, as exemplified by the cases of Bean, among which a number of callosa of very large area were from low-class whites and even from negroes.

THE MEMBRANES OF THE BRAIN.

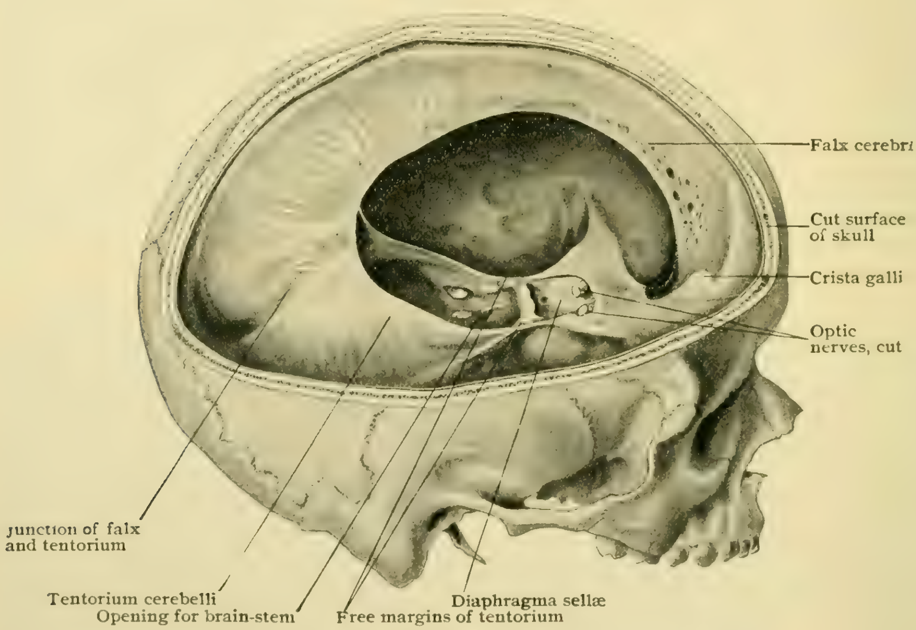
Like the spinal cord, the brain is enveloped by three membranes, or **meninges**, which, from without inward, are: (1) the *dura mater*, (2) the *arachnoid* and (3) the *pia mater*. The first of these is closely applied to the inner surface of the cranium, of which it constitutes the periosteum, and, in addition, by means of its processes serves to support and guard from undue pressure the enclosed mass of nervous tissue. The pia mater is the vascular tunic carrying the blood-vessels for the nutrition of the brain and, therefore, lies in contact with all parts of the external surface of the organ; whilst the arachnoid, the thinnest and most delicate of the three coats, is free from blood-vessels but is intimately related with the intracranial lymph-paths. Although the dura and the pia are closely attached to the skull and the brain respectively, they are separated by an interval which, in turn, is subdivided into two compartments by the arachnoid. The outer of these clefts lies between the dura and the arachnoid and is called the **subdural space**; the other, between the arachnoid and the pia, is the **subarachnoid space.** The first of these spaces is usually a mere capillary cleft, the arachnoid lying against the dura, and contains a small amount of a clear light straw-colored fluid of the nature of lymph. The second one, although much more capacious than the subdural, is crossed by so many trabeculæ of arachnoid tissue that in many places it acquires the character of a sponge-like tissue, rather than of an unbroken channel. Whilst anatomically the subdural and the subarachnoid spaces are distinct and nowhere communicate, as demonstrated by careful artificial injections into the subdural cleft, it is probable that during life the cerebro-spinal fluid finds its way through the thin partition of arachnoid tissue and enters the subdural space. The interstices of the arachnoid are filled with the cerebro-spinal fluid, a modified lymph, which is produced by the choroid plexuses within the ventricles. After distending these cavities, the fluid gains the subarachnoid space by way of the foramen of Magendie and the foramina of Luschka situated in the attenuated roof of the fourth

[1] Die Grosshirnrinde des Menschen, 1907
[2] Amer. Journal of Anat., vol. v., 1906.
[3] Amer. Journal of Anat., vol. iv., 1905.

ventricle (page 1100). The paths by which the fluids collected within the brain-membrane are carried off, thereby insuring under normal conditions the prevention of excessive intracranial tension, will be considered with the description of the dura and arachnoid, suffice it here to mention the sheaths contributed by these envelopes along the nerve-trunks as they leave the cranium and the Pacchionian bodies as the most important.

The Dura Mater.—This structure (**dura mater encephali**) is a dense and inelastic fibrous membrane, which lines the inner surface of the cranial cavity and sends partitions between the divisions of the brain. In contrast to its relation within the vertebral canal, where it is separated from the bony wall by a considerable space (page 1022), within the brain-case the dura everywhere lies closely applied to the bone—a relation essential in fulfilling its function as a blood-carrying organ for the nutrition of the cranium. Around the margins of the larger foramina, over the projecting inequalities of the fossæ and along the lines of the more important sutures, the attachment of the dura to the skull is particularly close, and at some of these points

Fig. 1033.



Portion of skull removed, showing partitions of dura in place.

—the foramina and the ununited sutures—the dura is continuous with the periosteum covering the exterior of the skull. On separating the dura from the bone, as may be readily done beneath the calvaria, except along the line of the sagittal suture, its outer surface is marked with the conspicuous ridges produced by the meningeal blood-vessels, which lie much nearer the outer than the inner surface of the membrane and hence give rise to the corresponding furrows seen on the inner aspect of the skull. In addition, the roughened surface of separation is beset with fine fibrous processes, the larger of which contain minute blood-vessels, that have been drawn out of the canals affording passage for the nutrient twigs. The inner aspect of the dura, on the contrary, is smooth and shining and clothed with a layer of endothelium which lines the outer wall of the subdural space. As the nerves enter the foramina in their exit from the cranium, they receive a tubular prolongation of the dura which accompanies the nerve-trunk for a short distance as the *dural sheath*, separated from the nerve by the underlying subdural cleft, and finally becomes continuous with the epineurium, whilst the subdural space communicates with the lymph-clefts within the connective tissue envelopes of the nerves. The dural sheath

surrounding the optic nerve through its entire length is noteworthy on account of its unusual thickness and completeness (page 1223).

The two layers of which the dura is composed are, for the most part, so closely united that only a single membrane is demonstrable. The division into two layers, however, is evident in certain localities, particularly in the middle fossa at the base of the skull. Here, on each side of the body of the sphenoid bone, the layers separate to form the cavernous sinus and, within the sella turcica, enclose the pituitary body. Over the apex of the petrous portion of the temporal bone they include between them a space, the *cavum Meckelii*, which lodges the Gasserian ganglion, whilst over the aquæductus vestibuli the dilated end of the endolymphatic duct, the saccus endolymphaticus, continued from the membranous labyrinth, lies between the two layers of the dura. Further, along the lines of its attachment to the skull beneath the sagittal suture, to the crucial ridges on the occipital bone and to the ridges of the petrous bones, the inner layer of the dura separates from the outer and forms partitions, which project inward and imperfectly subdivide the cranial cavity into compartments occupied by the larger divisions of the brain, as well as enclose the blood-spaces, known as the *dural sinuses*. These spaces have been described with the veins (page 867) and will be here only incidentally mentioned in connection with the partitions in which they lie. On either side of the superior longitudinal sinus, the layers of the dura exhibit local areas of separation, which prolong laterally the lumen of the venous channel. These parasinoidal spaces, the *lacunæ venosæ laterales*, are of consequence as receiving many of the cerebral veins and as affording additional localities in which the Pacchionian bodies may come into relation with the blood-stream. The septa thus formed by duplicatures of the inner dural layer are: (1) the *falx cerebri*, (2) the *tentorium cerebelli*, (3) the *falx cerebelli*, and (4) the *diaphragma sellæ*.

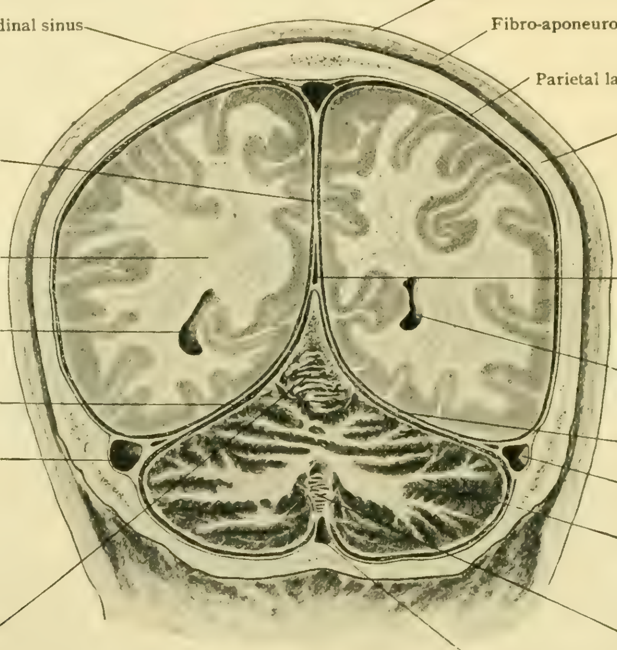
The **falx cerebri** is a sickle-shaped partition which occupies the greater part of the longitudinal fissure separating the cerebral hemispheres. Its upper and longer border is attached in the mid-line and extends from the cristi galli of the ethmoid bone in front to the internal occipital protuberance behind and encloses the *superior longitudinal sinus*. The latter channel appears triangular in cross-section (Fig. 1034), the upward placed base being the outer or parietal layer of the dura and the sides the separated lamellæ of the falx. The lower and shorter border of the falx is free and more sharply arched than is the upper, and extends from the hind part of the cristi galli to the highest point of the tentorium. Within its posterior half it encloses the *inferior longitudinal sinus*. The base of the falx is oblique, approximately at 45° with the horizontal plane, and attached to the upper surface of the tentorium in the sagittal plane. Along this junction lies the *straight sinus*. The narrow forepart of the falx is the thinnest portion of the partition and is often, more especially during the latter half of life, the seat of perforations, which may be so numerous as to reduce this part of the septum to a fenestrated membrane. Occasional deposits of true bone are found within the falx, which may be without pathological significance and represent the constant ossification of this partition seen in some aquatic mammals.

The **tentorium cerebelli** is the large tent-like partition that roofs in the posterior fossa of the skull and separates the cerebellum from the overlying posterior parts of the cerebral hemispheres. In its general form it is crescentic, the longer convex border lying behind and attached to the posterior and lateral margins of the posterior cranial fossa, and the shorter concave anterior border curving backward and upward from the anterior clinoid processes. The upper surface of the tentorium is attached by its entire width to the falx cerebri along the mesial plane, and in this manner the partition is maintained in a tensed condition. The sides of the tent-like fold are, however, not simply flat, but present a slight downwardly directed convexity in both the sagittal and frontal planes. The peculiar curvature of the under surface of the tentorium is reproduced, in reversed relief, by the upper aspect of the cerebellum which is accurately applied to the partition.

The *posterior border* of the tentorium is attached to the horizontal ridge crossing the occipital bone; farther outward, on each side, it is fixed to the postero-inferior angle of the parietal bone and, continuing forward and inward, to the upper border

of the petrous portion of the temporal bone, and thence to the posterior clinoid process. From the internal occipital protuberance as far as the parietal bone, this line of attachment corresponds with the course of the enclosed *lateral sinus* (page 867); but beyond, the venous channel leaves the tentorium in its descent to the jugular foramen, the farther attachment of the tentorium enclosing the *superior petrosal sinus*. Since the anterior border of the tentorium springs, on each side, from the anterior clinoid process, it follows that the two margins of the crescentic septum intersect in advance of the apex of the petrous bone, the posterior border turning inward to the posterior clinoid process, whilst the anterior margin is connected with the anterior process. The free tentorial border, in conjunction with the dorsum sellæ, defines an arched opening, the *incisura tentorii*, through which the mesencephalic portion of the brain-stem is continued into the cerebral hemispheres, the highest point of this aperture lying just behind the splenium of the corpus callosum.

FIG. 1034.



Frontal section of head, viewed from behind, showing relations of dura mater to cerebral hemispheres and cerebellum and position of sinuses.

The **falx cerebelli** is a small sickel-shaped dural fold which descends in the mid-line from the under surface of the tentorium, with which its broader upper end is attached, towards the foramen magnum. In the vicinity of this opening its apex bifurcates into smaller folds that fade away on either side of the foramen. Its posterior border, attached to the vertical internal occipital crest, contains the small *occipital sinuses*, or sinus when these channels are fused. The narrow crescent projects into the posterior cerebellar notch and thus intervenes between the hemispheres of the cerebellum.

The **diaphragma sellæ** is an oval septum of dura, which roofs in the pituitary fossa and is continuous on either side with the visceral or inner layer of the wall of the cavernous sinus. The diaphragm contains a small aperture, the *foramen diaphragmatis*, through which the infundibulum connects the enclosed pituitary body with the brain.

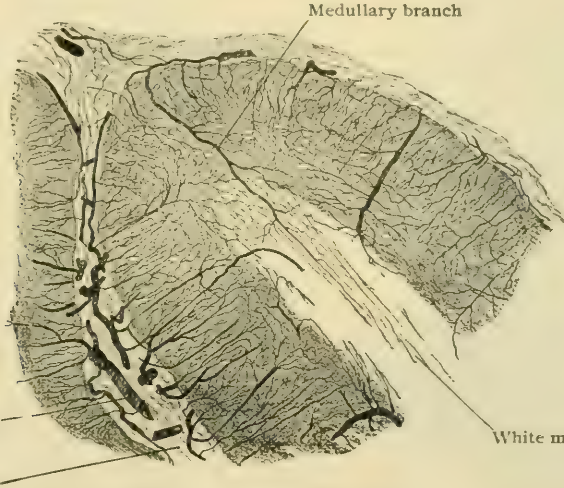
The **structure** of the dura presents the histological features of dense fibroelastic tissue, in which the elastic constituents, however, are greatly overshadowed by the white fibrous bundles. The inner surface of the dura is covered with endo-

thelial plates which constitute the immediate outer wall of the subdural lymph-space. Patches of endothelium sometimes seen on the external aspect of the membrane are regarded as indications of uncertain *epidural lymph-spaces*. The outer or periosteal lamella is less compact and richer in cells than the inner layer and contains a wide-meshed net-work of capillary blood-vessels. The larger bundles of fibrous tissue are disposed with some order so that a definite radiation from the two ends of the falx cerebri may often be recognized. Within the last-named fold, from the point where the free border of the falx and that of the tentorium meet, the fibres radiate towards the convex attached margin, some, therefore, arching far forward. From the same point the fibres within the tentorium pass laterally.

Minute calcareous concretions, also known as *brain-sand* or *acervulus*, are not infrequently found in the otherwise normal dura, especially in subjects of advanced years. They consist of aggregations of particles of calcium carbonate and phosphate arranged in concentric layers and surrounded by a capsule of fibrous tissue. They seldom exceed a diameter of .070–.080 mm., but may be so numerous that a distinctly gritty feel is imparted to the inner surface of the dura.

The **blood-vessels** within the dura are the branches of the meningeal arteries, and their accompanying veins, derived from various sources—from the ophthalmic,

FIG. 1035.



Portion of injected cerebral cortex, showing capillary supply of gray and white matter. × 18.

internal maxillary, vertebral, ascending pharyngeal and occipital arteries. They are destined, for the most part, for the nutrition of the skull, which they enter as minute twigs through innumerable openings in the bone. Some few *perforating arteries* traverse the bone and communicate with the pericranial vessels, whilst others are distributed to the tissue of the dura itself.

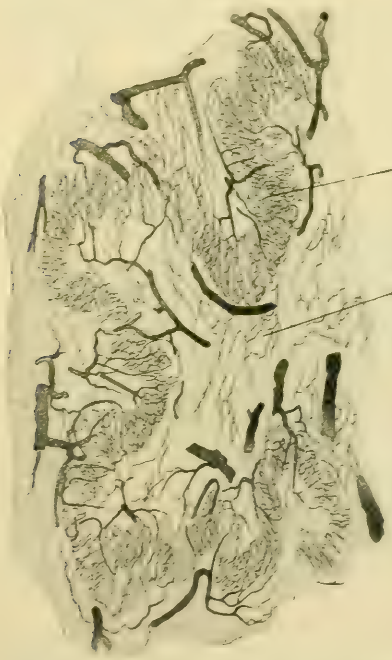
Definite **lymphatics** have not been demonstrated within the dura, the system of absorbent vessels being represented within this membrane by numerous lymph-spaces within the connective tissue stroma. These communicate indirectly with the subdural lymph-space, the contained fluid escaping at the foramina chiefly into the lymph-paths surrounding the cranial nerves, but to some extent also directly into the venous sinuses around the Pacchionian bodies.

The **nerves** of the dura include principally sympathetic filaments, distributed to the blood-vessels and to the bone, and sensory fibres. The immediate sources are the meningeal twigs contributed by the trigeminus, the vagus and the hypoglossal nerves. Those from the last source, apparently from the twelfth, are really sensory fibres from the upper cervical spinal nerves and sympathetic filaments from the cervical sympathetic cord ; in the other cases, the sensory fibres are probably accompanied by sympathetic filaments, which secure this companionship by means of

the communications which these cranial nerves have with the plexuses surrounding the arteries or with the superior cervical ganglion. The sensory nerves of the dura form a rich net-work of delicate twigs from which filaments have been traced to the inner surface in relation to which some end in bulbous expansions.

The Pia Mater.—This membrane (**pia mater encephali**) lies next the nervous substance and, being the vascular tunic supporting the blood-vessels for the nutrition of the brain, follows accurately all the inequalities of its exterior. It not only closely invests the exposed surface of the cerebrum and cerebellum, but penetrates along the sides and to the bottom of all the fissures as well, although within the small shallow fissures of the cerebellum a distinct process of pia mater can not be demonstrated. Additionally, in certain places where the wall of the brain-tube is very thin, the pia pushes before it the attenuated layer and seemingly gains entrance into the ventricles. Examples of such invagination are afforded in the relations of the velum interpositum and the choroid plexuses to the lateral and third ventricles (page 1162) and of the similar plexuses in the roof of the fourth ventricle (page 1100). The pia also contributes a sheath to each nerve, or to its larger component bundles, as the nerve leaves the brain at its superficial origin, which sheath surrounds the nerve during its intracranial course and for a variable distance beyond its emergence from the dural sac.

FIG. 1036.



Portion of injected dentate nucleus of cerebellum, showing capillary supply of internal nucleus. × 20.

The pia is so thin that the larger vessels, especially at the base of the brain, lie within the subarachnoid space, although in most cases they are enclosed within a delicate investment of pial tissue. The smaller vessels, however, ramify within the pia and in this situation divide into the twigs which directly enter the subjacent nervous tissue. As they penetrate the latter they are accompanied by a sheath of pia, which thus gains the nervous substance within which it follows the subdivisions of the arteriole, even their smallest ramifications.

Whilst within the pia the larger arteries form frequent anastomoses, the smaller twigs remain isolated and, being "end-arteries," on entering the subjacent gray matter break up into terminal ramifications which furnish the only supply for a particular district. The capillary net-work within the cortical gray matter is much closer than that within the subjacent white matter (Fig. 1035), in which the vessels are comparatively meagre. Here and there larger *medullary branches* are seen traversing the cortex, to which they contribute but few twigs, to gain the white matter within which they find their distribution. The contrast in richness between the supply of the gray substance and that of the adjoining white matter is not limited to the cerebral cortex, but is also well shown when the internal nuclei are examined (Fig. 1036). The veins emerge from the surface of the brain, but do not retain a definite relation to the arteries, since, instead of following the latter to their points of entrance, they for the most part seek the dural sinuses into which they empty.

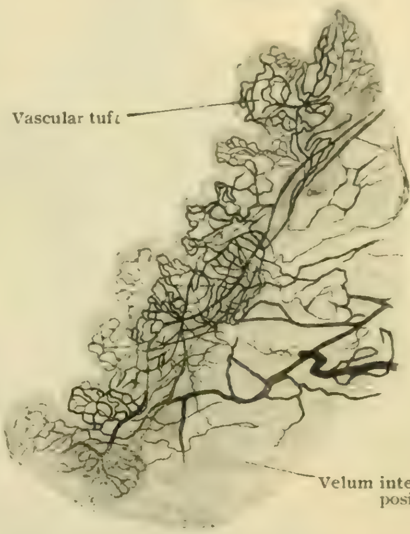
The special invaginating layers of pia mater, the *velum interpositum* (page 1162) and the *choroid plexuses* of the lateral and third ventricles, and the *choroid plexus* of the fourth ventricle (page 1100) have been described in connection with the appropriate parts of the brain. Attention may be again called to the manner in which the velum interpositum and the associated plexuses are formed (page 1194), and to the

fact that the apparent ingrowth of the pia beneath the splenium and the fornix to reach its final position over the third and within the lateral ventricles never occurs, the growth actually taking place in the opposite direction, that is, from before backward (page 1194).

The **structure** of the pia mater presents little for special mention. The membrane consists essentially of a delicate connective tissue envelope in which interlacing bundles of white fibrous tissue, intermingled with elastic fibres and containing numerous nuclei, are the chief features. As the arteries leave the pia to enter the brain, they receive sheaths of pial tissue within which are prolonged the lymph-spaces enclosed between the trabeculæ of the pial membrane. Along the basal surface of the brain, especially on the ventral aspect of the medulla, the pia frequently contains deeply pigmented branched connective tissue cells. These may be so numerous, particularly in aged subjects, that the membrane appears of a distinct brownish hue.

The numerous **nerves** encountered within the pia mater are chiefly sympathetic filaments destined for the walls of the blood-vessels and derived from the plexuses surrounding the internal carotid and the vertebral arteries. Additional nerve-fibres, probably sensory in function, occur in small numbers. The mode of their ending is uncertain, although terminal bulbus expansions and tactile corpuscles have been observed.

FIG. 1037.



Small portion of injected choroid plexus of lateral ventricle; surface view.

The Arachnoid. — This covering (**arachnoidea encephali**), the intermediate membrane of the brain, is a delicate connective tissue envelope that intervenes between the dura externally and the pia internally. In contrast to the last-named membrane, which follows closely all the irregularities of the sunken as well as of the free surface of the cerebrum, the arachnoid is intimately related to the convolutions only along their convexities, and on arriving at the margins of the intervening fissures stretches across these furrows to the convolutions beyond. From this arrangement it follows that intervals, more or less triangular on section, are left over the lines of the fissures between the arachnoid and the fold of pia which dips into the sulcus. These clefts form a system of intercommunicating channels which are parts of the general subarachnoid space. Over the summits of the convolutions, the arachnoid and pia are so intimately united that they constitute practically a single membrane, whilst, where parted by the subarachnoid space, they are connected only by the trabeculæ of arachnoid tissue. In many places, however, where the intervening cleft is not wide, these trabeculæ are so numerous that the space is occupied by a delicate reticulum and becomes converted into a layer of loose subarachnoid tissue. Where, on the other hand, the arachnoid encloses spaces of considerable size, as it does on the basal surface of the brain, the trabeculæ are reduced in number to relatively few long, cobweb-like threads that extend from the arachnoid to the pia mater. Over the upper and outer aspects of the cerebrum and cerebellum the arachnoid follows, in a general way, the contour of the brain. On the ventral surface, however, it bridges from the median elevation presented by the brain-stem to the adjacent prominences offered by the cerebellum and the cerebral hemispheres The irregular spaces thus enclosed contain considerable quantities of cerebro-spinal fluid and are known as the **cisternæ subarachnoidales**, of which several subdivisions are recognized according to locality.

The **cisterna magna** (**cisterna cerebellomedullaris**), the largest of these spaces, overlies the dorsal surface of the brain-stem and is continuous through the foramen

magnum with the posterior part of the subarachnoid space of the cord. The arachnoid passes from the back part of the under aspect of the cerebellum to the posterior surface of the medulla and thus encloses a considerable space which at the sides of the medulla is continuous with the upward prolongation of the anterior subdural space of the cord. The lower part of the brain-stem is thus completely surrounded by the subarachnoid cavity. The ventral surface of the pons is enveloped by the upward extension of the anterior part of the spinal arachnoid, the cleft so enclosed constituting the **cisterna pontis,** of which a median and two lateral subdivisions may be recognized. From the upper ventral border of the pons the arachnoid passes forward to the orbital surface of the frontal lobes, covering the corpora mammillaria, the infundibulum and the optic chiasm, and laterally to the adjacent projecting temporal lobes and thence, covering in the transverse stem of the Sylvian fissures,

FIG. 1038.

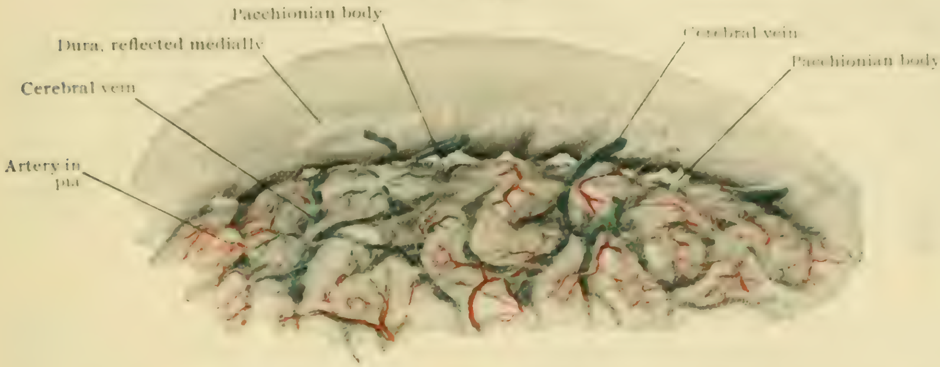
Inferior aspect of brain covered with pia and arachnoid, showing large subarachnoid spaces.

to the frontal lobes. This large space, which includes the deep depression on the basal surface of the brain, is the **cisterna basalis.** It is imperfectly subdivided by incomplete septa of arachnoid tissue into secondary compartments, one of which lies between the peduncles (**cisterna interpeduncularis**), another behind the optic commissure (**cisterna chiasmatis**) and a third above and in front of the chiasm (**cisterna laminae terminalis**). Anteriorly the cisterna basalis is continued over the convex dorsal surface of the corpus callosum (**cisterna corporis callosi**), and on either side along the stem of the Sylvian fissure (**cisterna fissurae lateralis**). Within the median region of the cisterna basalis lie the large arterial trunks forming the circle of Willis. These vessels are invested with delicate sheaths of arachnoid, which accompany the smaller branches until they enter the vascular membrane to become pial vessels.

The arachnoid also contributes sheaths to the cranial nerves as they pass from their superficial origins to the points where they pierce the dura, these sheaths overlie those derived from the pia and, as do the latter, accompany the nerve-trunks for a

variable but usually short distance beyond their emergence from the dural sac. The arachnoid sheath is especially well marked along the optic nerve, which it follows as far as the eyeball, and completely subdivides the space between the pial and dural

FIG. 1039.



Portion of superior surface of right hemisphere covered by pia and arachnoid; dura has been partly separated and reflected towards mid-line to expose Pacchionian bodies and cerebral veins, which are seen entering superior longitudinal sinus.

sheaths into a subdural and a subarachnoid perineural compartment, directly continuous with the corresponding intracranial spaces.

As previously noted, the cerebro-spinal fluid secreted within the ventricles escapes through the openings in the roof of the fourth ventricle—foramen of Magendie and the foramina of Luschka (page 1100)—into the subarachnoid space. After filling the cisterna magna and the other large spaces on the basal surface of the brain and surrounding the spinal cord, the fluid finds its way into the smaller spaces on the exterior of the cerebrum. In this manner the entire mass of nervous tissue is enveloped by a more or less extensive cushion of fluid which, particularly at the base of the brain, is well adapted to protect the enclosed delicate structures from undue concussion. Since the cerebro-spinal fluid is being continuously secreted, it is evident that some adequate means of escape must be provided to insure, under normal conditions, the maintenance of intracranial and intracerebral pressure within due limits. The paths by which this is accomplished include: (1) the extension of the subarachnoid space along the nerve-trunks, and (2) the villous projections of arachnoid tissue, the Pacchionian bodies, along the course of the dural blood-sinuses.

FIG. 1040.

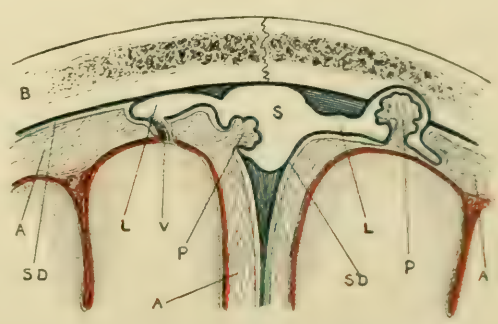


Diagram showing relations of Pacchionian bodies to blood-spaces and dura; *B*, bone, *S*, longitudinal sinus; *L*, lacunæ; *P*, Pacchionian bodies; *V*, cerebral vein emptying into lacuna; *SD*, subdural space; dura is blue and pia is red, intervening tissue is arachnoid; *A*.

The **Pacchionian bodies** (**granulationes arachnoidales**) are numerous cauliflower-like excrescences of the arachnoid, for the most part small but occasionally reaching a diameter of 5 mm. or over, which lie on the outer surface of the membrane along the course of the dural venous sinuses. Their favorite site is on either side of the superior longitudinal sinus, where they occur in groups, although they occur in smaller number and size in connection with other sinuses, as the lateral, cavernous and straight. They consist entirely of arachnoid tissue and contain no blood-vessels. Although lying mostly at the side of the longitudinal sinus with which they are then indirectly related through the lateral diverticula, the *lacunæ laterales* or *blood-lakes*, in some instances

they encroach upon the lumen of the main channel itself, within which they appear as irregularly rounded projections on its lateral walls. Whatever their relation, whether with the sinus or the lateral diverticula, the Pacchionian bodies never lie free within the blood-space, but are always separated from the latter by the dural wall. Over the summit of the elevation the dura becomes greatly attenuated, but never entirely disappears, so that only a thin membrane and the subdural cleft, theoretically present but practically more or less obliterated, intervene between the subarachnoid spaces and the blood-stream. This partition offers little obstruction to the passage of the cerebro-spinal fluid, which, unless the pressure within the venous channel is higher than that within the subarachnoid space, passes from the latter into the sinus and thus relieves the intracranial tension. When well developed, as they often are after adolescence but never during childhood when they are small and rudimentary, the Pacchionian bodies are frequently lodged in depressions within the calvaria, whose inner surface is sometimes so deeply pitted that the bone in places is translucent.

THE BLOOD-VESSELS OF THE BRAIN.

The course and distribution of the individual blood-vessels supplying and draining the nervous tissue of the brain have been described in the sections on the Arteries (page 746) and the Veins (page 861). It remains, therefore, only to consider at this place the more general relations concerning these vessels.

The **arteries** supplying the brain are derived from two chief sources—the internal carotid and the vertebral arteries. After entering the cranium these vessels and their branches form the remarkable anastomotic circuit known as the circle of Willis (page 760). The latter gives off, in a general way, two sets of branches, the **ganglionic**—for the most part short vessels which soon plunge into the nervous mass to supply eventually the overlying internal nuclei, the corpora striata and the optic thalami—and the **cortical**, which pursue a superficial course and are carried by the pia mater to all parts of the extensive sheet of cortical gray substance, as well as to the subjacent tracts of medullary white matter.

The **medulla oblongata** and the **pons** are supplied by branches from the anterior spinal, the vertebral, the basilar and the posterior cerebral arteries. These branches gain the nervous substance as two sets, the radicular and the median. The *radicular branches* follow the nerve-roots and, just before reaching the superficial origins of the nerves, divide into peripheral and central twigs, the former being distributed superficially and the latter following the root-fibres to their nuclei. The *median branches* are numerous minute vessels which ascend within the median raphe towards the floor of the fourth ventricle and assist the centrally directed twigs of the radicular branches in supplying the nuclei of the nerves situated within that region. Those supplying the nuclei of the hypoglossal and the bulbar portion of the spinal accessory nerves are derivations from the anterior spinal arteries; those to the nuclei of the vagus, the glosso-pharyngeal and the auditory are from the vertebral as they join to form the basilar; whilst those to the nuclei of the facial, the abducent and the trigeminal are from the basilar. The choroid plexus of the fourth ventricle is provided with branches from the posterior cerebellar arteries.

The **cerebellum** receives its supply from three arteries, the anterior and posterior inferior and the superior, cerebellar. The general course of these vessels is approximately at right angles to the direction of the fissures and folia of the hemispheres. In the **mid-brain** the *interpeduncular space* is provided with branches from the basilar and the posterior cerebral arteries; the *cerebral peduncles* with those from the posterior communicating and the terminal part of the basilar; and the *corpora quadrigemina* with those from the posterior cerebral, additional twigs passing from the superior cerebellar to the inferior colliculi.

The **thalamus** is supplied by branches, all end-arteries, from different sources, those for its antero-median portion being from the posterior communicating, those for its antero-lateral portion from the middle cerebral, whilst those for its remaining parts, as well as for the pineal and the geniculate bodies, are from the posterior cerebral. The last vessel also supplies the velum interpositum and the choroid plexus of the third ventricle.

The structures on the **base of the brain**, such as the corpora mammillaria, the tuber cinereum, the infundibulum and the pituitary body, receive twigs from the posterior communicating arteries. The optic chiasm and tract are supplied with branches from the anterior cerebral, the anterior communicating, the internal carotid, the posterior communicating and the anterior choroidal arteries.

The **corpus striatum**, both the caudate and lenticular nuclei, are supplied chiefly by branches from the middle cerebral artery, which pierce the anterior perforated space and, as the lenticular, lenticulo-striate and lenticulo-thalamic vessels, all end-arteries, traverse the lenticular nucleus and the internal capsule and terminate in the caudate nucleus and the thalamus. One of the lenticulo-striate arteries, which pierces the outer part of the putamen, was named by Charcot the "artery of cerebral hemorrhage" since it is frequently ruptured.

The **choroid plexus of the lateral ventricle** receives its blood-supply from the anterior and posterior choroidal arteries. The first of these, given off by the internal carotid artery, enters the anterior and lower part of the choroidal fissure and takes part in forming the most dependent portion of the vascular complex which overlies the hippocampus. The posterior choroidal artery, usually represented by a number of small twigs, is derived from the posterior cerebral and enters the upper part of the fissure. After supplying the velum interpositum, it completes the choroid plexus in the descending horn and in the body of the lateral ventricle.

The **cerebral hemispheres** are supplied by the cortical branches of the anterior, middle and posterior cerebral arteries. Of these the middle one is the largest and is distributed to the most extensive area, which embraces the greater part but not all of the external surface of the hemisphere. This vessel also supplies the outer half or more of the orbital surface and the anterior part of the temporal lobe. The anterior cerebral is essentially the artery of the mesial surface, the anterior two-thirds of which, in conjunction with an adjoining zone on the external and on the orbital surface, it supplies. The distribution of the posterior cerebral is chiefly on the mesial and tentorial surface of the occipito-temporal region, and in addition an adjoining strip along the postero-inferior margin of the hemisphere. It follows, therefore, that, with the exception of the occipital lobe, which is entirely supplied by the posterior cerebral artery, all of the conventional divisions of the hemisphere receive their arterial supply from more than a single source.

The **frontal lobe** is supplied by the anterior cerebral artery :—over its entire mesial surface ; over the superior and the anterior two-thirds of the middle frontal convolutions and the upper end of the precentral convolution ; and over the orbital surface internal to the orbital sulcus. Over all the remaining parts, the frontal lobe receives the branches of the middle cerebral artery.

The **parietal lobe** is supplied by the middle cerebral artery on the external surface, with the exception of a narrow strip along the upper border ; this zone, together with the mesial surface of the lobe, is supplied by the anterior cerebral artery. The **occipital lobe** is supplied exclusively by the posterior cerebral artery. The **temporal lobe** is supplied by the middle cerebral artery over its superior and the upper half of the middle temporal convolution with the tip of the lobe ; the remainder of the lobe receives the branches of the posterior cerebral.

The **limbic lobe** shares in the distribution of the anterior and posterior cerebral arteries, the district of the former including the gyrus callosum to the vicinity of the isthmus, whilst that of the posterior cerebral includes the remainder of the lobe.

The **veins** returning the blood from the brain are all tributaries of the dural sinuses, and they therefore only to a limited degree follow the course of the cerebral arteries. They are further distinguished by the absence of valves. The superior cerebral veins, after emerging from the surface of the brain, course within the pia over the convex aspect of the hemisphere and proceed, for the most part, towards the superior longitudinal sinus into which they open, either directly or through the lacunæ laterales, by from 12–15 trunks. The veins draining the structures situated around the lateral and third ventricles are tributary to the paired lesser veins of Galen, which run backward within the velum interpositum and, emerging below the splenium, unite to form the great vein of Galen. This vessel joins with the inferior longitudinal sinus to form the straight sinus, which is lodged in the line of juncture between the falx cerebri and the tentorium cerebelli.

PRACTICAL CONSIDERATIONS: THE BRAIN AND ITS MEMBRANES.

Congenital Errors of Development.—Various defects of development of the brain and its membranes are not uncommon. The brain may be absent (*anencephalus*), it may escape from the skull (*exencephalus*), the brain, membranes and vessels may be only rudimentary (*pseudencephalus*), or there may be arrest of development in any limited portion (*porencephalus*—a name more suitably applied when there is a marked depression in the surface of the brain). The brain as a whole may be defective (*microcephalus*), or it may be abnormally large (*macrocephalus*).

The most common enlargement of the head, *hydrocephalus*, is due to a retention of cerebro-spinal fluid within the cranium, ordinarily within the ventricles, but sometimes in the subarachnoid space. It is usually a congenital condition ; its cause is not clearly known. It is believed by many that it is due to a prenatal inflammation of the ventricular ependyma, and by others to a disarrangement of the orifices of communication between the ventricles (Luschka, Monro, and Neurath). The aqueduct of Sylvius has been found obliterated, and inflammatory processes have been seen about the foramen of Monro.

Congenital defective ossification of the skull may result in a gap through which may protrude a portion of the meninges with or without brain substance. If such a protrusion consists of a meningeal sac containing only fluid, it is called a *meningocele*. If it contains a portion of the brain also, it is an *encephalocele*, and if the protruded portion of the brain encloses a portion of a ventricle, a *hydrencephalocele*. Such tumors may be concealed from view at the base of the skull, or in the pharynx, or may protrude into the nose or orbit. They are usually in the median line and most frequently in the occipital region. Next in frequency they occur at the fronto-nasal suture, and more rarely in other parts of the skull. Pressure on the tumor will often reduce it partly or completely within the cranium, but in the latter case symptoms of pressure on the brain will arise. Violent expiratory efforts, as in crying or coughing, which increase the cerebral congestion, render the tumor more tense.

The Meninges.—Diseases of the meninges are relatively more common than those of the brain proper, and many conditions often spoken of as brain diseases are affections of the meninges, the pia being closely adherent to the brain and extending into the fissures. Inflammation of the dura is called *pachymeningitis*, of the pia and arachnoid together *lepto-meningitis.*

External pachymeningitis is usually secondary to disease of the cranial bones, traumatism, infection, or tumors. It is most frequently the result of ear disease, and is therefore generally of surgical interest.

Internal pachymeningitis is apt to be associated with effusions of blood into the subdural space ; they may cover a considerable area without producing marked symptoms, or they may be encapsulated (hæmatomata of the dura mater), and may reach the size of a man's fist, causing compression of the brain. Occasionally they become purulent. The blood or pus may gravitate to the base of the brain in the region of the cerebellum, pons, and medulla, when the pressure symptoms will be more serious ; or it may find its way into the spinal canal.

The dura is especially adherent at the base of the skull and, to some degree, at the sutures of the vault. In the rest of the vault it is loosely attached, and according to Tillaux, particularly so in the temporal region. Collections of blood may accumulate between the dura and the bone (*extradural hemorrhage*). This variety of intracranial hemorrhage is commonly the result of rupture of one of the branches of the middle meningeal artery in the temporal region, the effused blood separating the loosely attached dura. If the blood is poured out rapidly, compression symptoms will soon appear, but if the hemorrhage is slow, the escape of cerebro-spinal fluid into the spinal canal permits of more delay in the appearance of those symptoms. The patient has often time to recover, at least partially, from the unconsciousness of concussion before that of compression appears ; and it is this recovery of intelligence which is most characteristic of the condition. There will often be localizing symptoms indicating the part of the brain cortex which is irritated or compressed.

Subdural hemorrhage may follow the rupture of a number of small vessels, either of the pia or dura under a depressed fracture ; or it may come from a large vessel, particularly the middle cerebral. The symptoms and treatment are very much the same as in the extradural variety.

In children extradural hemorrhage is very rare, because of the relatively firmer attachment of the dura during the period of growth. The blood may escape under the scalp through a line of fracture in the skull ; or, what is more likely, it may pass through a tear in the dura into the subdural space. In fractures of the base of the skull, at any age, owing to the adhesion of the dura, the latter is likely to be torn ; cerebro-spinal fluid may escape into the adjacent air cavities, as into the nose, pharynx or middle ear. A close adhesion of the dura to the bone, as sometimes found at

operation, indicates a previous inflammation, as does any tendency of the arachnoid to adhere to the dura, since these two are normally not adherent. The arachnoid, however, is normally closely attached to the pia, and for practical purposes they are usually considered as one layer, the lepto-meninx.

Inflammation of this layer—*lepto-meningitis*—may attack the convexity or the base of the brain, and may be primary or may be secondary to other diseases, usually purulent infections. It is asserted that the primary disease attacks, as a rule, the base, the secondary, the convexity of the brain; but this is not beyond dispute.

Tuberculous meningitis is frequently found at the base, but miliary tubercles are not uncommon on the convexity of the brain. The exudate which is deposited at the base frequently leads to irritation or paralysis from pressure on the cranial nerves in close relation to the under surface of the brain. Tumors growing at the base of the brain produce localizing symptoms early by pressing on the adjacent cranial nerves. A single nerve may be involved, but more commonly a combined paralysis from involvement of several nerves results.

The *cerebro-spinal fluid* is found in the subdural and subarachnoid spaces, and in the ventricles. Over the vault it is comparatively scanty in both spaces. At the base, however, in the subarachnoid space of the middle and posterior fossæ, it is abundant, forming an excellent support and protection to the most delicate part of the brain, that containing the vital centres. The frontal lobes, of much less importance as to vital function, rest directly on the bone in the anterior fossa; and are therefore more subject to direct traumatic influences. The fact that the subarachnoid space is continuous with the ventricles through the foramina of Magendie and of Luschka, and communicates freely at the foramen magnum with the subarachnoid space of the cord, explains how excess of pressure within the cranium at one part may be relieved by escape of fluid to other parts. It explains also why pressure on a spina bifida will sometimes produce symptoms of cerebral compression; and vice versa, why the increased congestion of the cerebral vessels from expiratory efforts, as in coughing, will increase the tension in the spinal tumor.

Occlusion of the foramen of Magendie, by the products of inflammation, may cause increase of fluid from retention in the ventricles, with the development of *hydrocephalus*, and it is in this way that internal hydrocephalus occasionally follows meningitis. For the purpose of determining the cause of this condition, subarachnoid fluid is sometimes withdrawn through a hollow needle.

The lateral ventricles can be tapped through a trephine opening 3 cm. (1¼ in.) behind the external auditory meatus, and the same distance above Reid's base line—drawn from the lower margin of the orbit through the middle of the external auditory meatus. The needle is passed towards a point on the opposite side of the skull, 6.5–7.5 cm. (2½–3 in.) vertically above the external auditory meatus. Under normal circumstances the ventricle is from 5–5.6 cm. (2–2¼ in.) from the surface, but if the ventricle is distended the distance is shorter.

By a trephine opening in the occipital bone in the subcerebellar region, the subarachnoid fluid has been reached at the base of the brain where it is most abundant.

Lumbar puncture for withdrawing cerebro-spinal fluid for diagnostic and therapeutic purposes is sometimes employed. The needle should be introduced between the third and fourth, or between the fourth and fifth lumbar vertebræ, at the level of the lower border of the spinous process, or opposite its lower third, and about 1 cm. from the median line. It should be passed somewhat upward between the sloping laminæ, and should be continued inward toward the canal until, by the diminished resistance, it is recognized that the point of the needle has entered the subarachnoid space.

The Brain.—Of all the affections of the brain, *hemorrhage* is the most frequent and most important, whilst in the spinal cord it is comparatively rare unless as a result of trauma. Hemorrhage from the meningeal vessels is most commonly due to trauma, but within the brain substance the usual cause is atheroma, sometimes with the production of miliary aneurisms. A sudden strain increases the intravascular tension and ruptures one of these diseased vessels, giving rise to pressure symptoms, depending on the seat and extent of the hemorrhage.

The cortex is supplied by pial vessels distinct from those supplying the basal ganglia and adjoining regions. The latter come directly from the branches of the circle of Willis at the base. The cortical vessels anastomose; those in the region of the basal ganglia do not. The latter are "end arteries," so that when one is plugged by an embolus the part supplied is deprived of blood and undergoes necrosis (softening of the brain). In such a case the cortical supply would not be permanently interfered with. When a cortical arteriole is blocked, the anastomosis may furnish a sufficient collateral circulation to prevent necrosis in the affected part, but cortical softening is exceedingly common. When one of the arteries forming the circle of Willis is occluded, as an internal carotid by ligation of the common carotid, the anastomosis in the circle is so free that, in most cases, no marked effect is apparent. Cerebral disturbances, as delirium or convulsions, do occur in some cases, and in some are fatal. Even when both carotids are ligated, with an interval of some days or weeks, the operation is not more frequently followed by cerebral disturbances than when only one is tied (Pilz). A case in which the patient lived after one carotid and one vertebral had been obliterated by disease, and the other carotid ligatured, has been reported (Rossi). In another case, although both carotids and both vertebrals had been occluded, the patient lived a considerable time afterward, the cerebral circulation being maintained through the medium of anastomosis of the inferior with the superior thyroids, and the deep cervical with the occipital artery (Davy). Occasionally ligation of the carotid has been followed by hemiplegia.

The most common seat of intracerebral hemorrhage is near the basal ganglia in the region of the internal capsule. The artery most frequently at fault is a branch of the middle cerebral, the *lenticulo-striate*, or *artery of Charcot* (page 1207). Hemorrhages occur with less frequency in other portions of the cerebrum, and much more rarely in the pons, medulla oblongata, and cerebellum. The symptoms produced by the hemorrhage are the result of destruction of tissue and of pressure upon adjacent parts, and will vary according to the seat of the lesion. Tumors or inflammatory products will produce essentially the same symptoms.

Cerebral Localization.—In order to understand the nature of the symptoms produced by brain lesions it will be necessary to study at least some of the functional areas of the cortex and their paths of conduction through the brain substance.

Taylor has summarized as follows the researches of His and of Flechsig, which are of comparatively recent date and have thrown new and valuable light upon the functions possessed by the cortical regions of the brain, by the study of their mode of development. Flechsig succeeded in following the various tracts through their myelination. The tracts which are functional earliest receive their myelin before the others. He has shown that the fibres in the spinal cord, medulla, pons and corpora quadrigemina are almost entirely medullated when the higher parts show little or no myelin. In the new-born child the cerebrum is almost entirely immature, and proportionately few of its fibres are medullated.

According to Flechsig, the sensory paths in the brain first become medullated, and may be observed developing one after another, beginning with that of smell and ending with that for auditory impulses from the periphery to the cortex. In this way it has been ascertained that the individual sensory paths terminate in tolerably sharply circumscribed cortical regions, for the most part widely removed from one another, being separated by masses of cortical substance which remain for a considerable period immature or undeveloped. The cortical sense areas thus mapped out correspond entirely to those regions of the surface of the brain which pathological observation has shown to stand in relation to the different qualities of sensation. *Olfactory fibres* are found to end mainly in the uncinate gyrus. *Visual fibres* have been traced to the occipital lobe in the neighborhood of the calcarine fissure, and *auditory fibres* to the temporal lobe. Flechsig has further observed that new paths begin to develop from the points where certain of the sense fibres terminate and pursue a downward course. They can be followed from the cortex to the medulla and to the motor nuclei of the cord. These descending paths are mainly those known as the *pyramidal* or *motor tracts*, and the area from which they proceed, commonly called the Rolandic region, is, according to Flechsig, concerned also in the sensation

of touch; he calls it the *somæsthetic area*. It includes the precentral and postcentral convolutions, the paracentral lobule. The sensory fibres passing from the periphery to this area would appear to excite sensations of touch, pain, temperature, muscle- and tendon-sense, equilibrium, etc. This cortical region probably represents a complex mass of sense centres rather than a single sensory area, and in addition to being a sensory field, the somæsthetic area is *the great motor region of the brain*.

When this sensory-motor area and the various sensory areas are fully taken into account, there still remain about two-thirds of the cortex which appear to have nothing to do with the periphery. Flechsig calls these regions of the cortex "*association centres*," as he believes they furnish arrangements for uniting the various central sense areas.

The best known cortical areas are the motor, speech, visual, and auditory, although new contributions to our knowledge are being made from time to time. Recently Grünbaum and Sherrington have demonstrated in the cortex of the higher apes, including the orang and several species of the chimpanzee and gorilla, that the motor area was found in the whole length of the precentral convolution and the en-

FIG. 1041.

Left cerebral hemisphere illustrating diagrammatically motor zone and its subdivisions. (*Mills.*)

tire length of the central fissure. It did not at any point extend behind the central fissure. They demonstrated other important facts in connection with this and other areas. These results have been in part at least confirmed by recent histological researches, and by faradization of the human brain during operation for the purpose of more accurately identifying the relations of the opening to the area to be exposed.

The most important, because the best known, area of the cortex, is that associated with the fissure of Rolando and the fissure of Sylvius.

Before the publication of the experiments and observations just alluded to, the motor zone was regarded as extending over both central convolutions which lie one anterior and the other posterior to the central fissure or fissure of Rolando, also over the paracentral lobule on the median aspect of the hemisphere, and to some extent into the posterior extremities of the first and second convolutions. The trend of opinion is now in favor of the view that the motor region is entirely or almost entirely in front of the central fissure (Monakow, Mills). This is, of course, a matter of considerable importance in trephining for a tumor or hemorrhage supposed to be situated in this area, as instead of making the opening directly astride of the fissure of Rolando it would be better, if these views are correct, to operate with the idea of exposing a region two-thirds or three-fourths in front and one-third or one-fourth behind the central fissure.

In the lower one-third or fourth of the motor zone are found the motor centres for the *face* and *tongue*, that is, for the facial and hypoglossal nerves. In the middle third or half are the *arm* centres. In the upper part of the region and paracentral lobe, are the centres for the *lower extremity*. Localized lesions of the motor zone may therefore produce a paralysis limited to one part controlled by the affected portion of the cortex, as of the face, arm or leg (monoplegia). The lesion is much more likely to involve two adjacent areas, as of the face and arm, or of the arm and leg, giving rise to a combined paralysis ; but no single lesion, unless it were crescentic in form, could involve at the same time the leg and face areas without including the intervening arm area.

Within each of the larger areas a more specialized differentiation is possible, although none of them can be sharply defined, not even the larger. That the facial centre lies in the lower part of the anterior central convolution is certain, and it is believed that the upper and lower muscles of the face are each represented by a separate centre. In the upper and forward part of the face-area are represented the movements of the cheek and eye-lids ; in the posterior part the movements of the pharynx, platysma and jaws.

FIG. 1042.

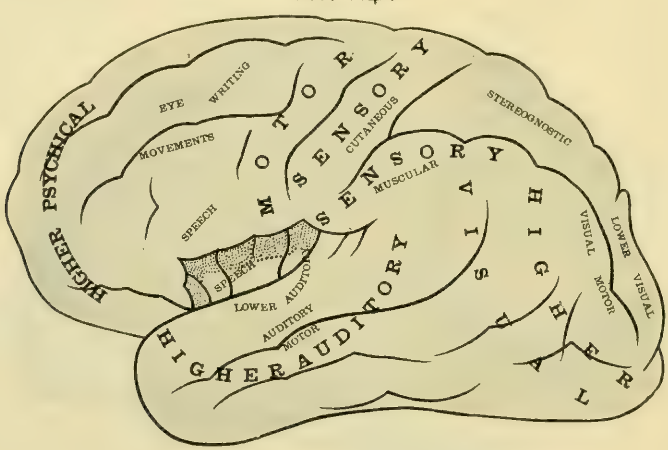


Diagram illustrating probable relations of physiological areas and centres of lateral aspect of left cerebral hemisphere. (*Mills.*)

In the arm-area it is considered as certain that the centre for the movements of the thumb and index finger is below; above is that for the finger and hands; and in the highest part is that for the shoulder. In the posterior parts of the second frontal convolution and in a portion of the third frontal convolution are the centres for the associated lateral movements of the eyes and lateral movement of the head (Beevor and Horsley).

Our knowledge of the more special localization within the leg centre is not at all exact, and the many views held are very contradictory. It is believed that the centres for the movements of the thigh, knee, foot, and toes, are arranged in the order named, from before backward on the lateral border of the hemisphere and in the paracentral lobe.

A narrow zone for the movements of the trunk, as shown by Grünbaum and Sherrington, is located between the upper border of the arm-area and the lower border of the leg-area. It is now considered probable, however, that the cutaneous sensory centres are posterior to and in close contact with the motor centres in the postcentral convolution, while other centres for stereognostic perception and the muscular sense are located in the superior and inferior parietal convolutions.

The *speech centres* are in the posterior part of the third left frontal convolution (Broca's convolution), in right-handed people in the first left temporal convolution, and perhaps in the left angular gyrus.

In Broca's convolution is probably the centre for *motor speech*, and a lesion here gives motor aphasia, an inability to transform concepts into words, although the patient is conscious and the tongue can be moved. A minor part in speech is played by the posterior part of the right third frontal convolution, but in the left-handed it is probably the chief centre.

In the first left temporal convolution is the *auditory centre* for *speech*, a lesion of which leads to a loss of memory for word-sounds, though the hearing may be undisturbed.

The centre for memory of *printed words* is probably in the left angular gyrus; and a lesion there probably causes a loss of the ability to read or to understand written language, though ordinary sight is undisturbed. The existence of a motor writing centre is doubtful (Oppenheim). If it exists, it is probably located in the posterior portion of the left second frontal convolution.

We have no definite knowledge of the location of centres for *smell* and *taste*. That for smell is thought to lie in the uncinate gyrus. The centre for taste has been supposed to be in the anterior portion of the gyrus fornicatus, but it is not decided, although it is probably near the centre for smell.

Fig. 1043.

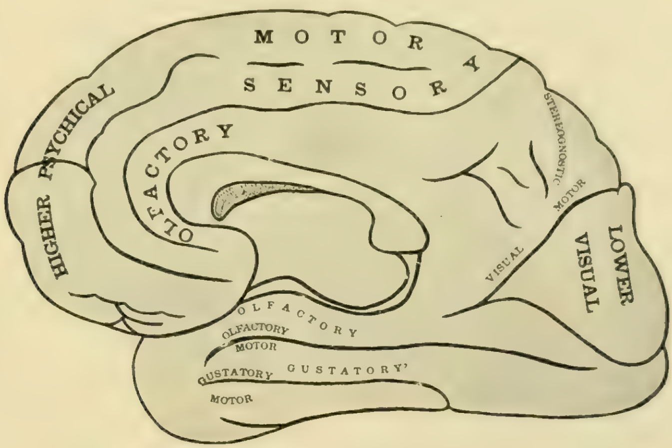


Diagram illustrating probable relations of physiological areas and centres of mesial aspect of right cerebral hemisphere. (*Mills.*)

The *auditory centre*, as indicated, is in the upper temporal convolution. It is very likely that the centre of each side is connected with both auditory nerves, so that a paralysis of one side by a unilateral lesion of one side may be compensated for by the centre of the opposite side.

It is probable that no part of the cerebral cortex is absolutely without function, although the functions of some areas are very little known. Unilateral disease of the anterior portion of the *frontal lobe* may be extensive without notable symptoms of any kind. The atrophy is often most marked here in general paralysis of the insane, and in other forms of dementia. It is generally agreed that the seat of "the higher psychical functions" is located in the prefrontal lobes, the left side being perhaps more active than in the right.

Reference has already been made to the relation of the occipital cortex to sight, and of the temporal to hearing. The cuneus and calcarine fissure together constitute a primary or lower cortical or visuo-sensory centre, while the lateral aspect of the occipital lobe is a visuo-psychic area, containing sub-areas or centres concerned with higher visual processes. Mind blindness, for instance, results from destructive lesion of the lateral occipital lobe, particularly if the lesion is a large one, in the left hemisphere, or if lesions of both occipital lobes are present. A lesion of the cuneo-calcarine cortex causes lateral homonymous hemianopsia. This may be produced

also by a lesion in the lateral portion of the occipital lobe, if it extends inwards sufficiently to interrupt the optic radiations.

In spite of extensive researches the functions of the *central ganglia* are very little known.

Lesions of the **cerebellar hemispheres** may not produce distinct phenomena until the median lobe or vermiform process is involved, when two especially characteristic symptoms will almost certainly develop. These are a peculiar disturbance of equilibrium with a staggering gait (cerebellar ataxia), and a troublesome vertigo. Although the patient can scarcely stand alone he may possibly be able to perform the most delicate movements with his upper extremities. The vertigo occurs only in standing or walking, and is then almost always present. Nystagmus is also a frequent symptom. Vomiting is very often present, but is not characteristic, since it is equally frequent in other brain diseases.

Extending along the floor of the aqueduct of Sylvius and of the fourth ventricle, that is, along the cerebral peduncles, pons and medulla, we find the nuclei of origin of the motor fibres of the *cranial nerves*. It should be borne in mind that the controlling centres of these nerves are in the cerebral cortex. Many automatic centres, as of circulation, respiration, sweating, and regulation of heat, as well as the motor and sensory tracts are found in the medulla.

Cranio-Cerebral Topography.—In order that the surgeon may expose and recognize certain areas of the cortex, it becomes very important that the relations between these areas and the corresponding external surface be well understood. For this purpose advantage is taken of the landmarks of the skull (page 241). From these bony points, ridges and depressions, by means of lines and measurements, the known cortical areas may be accurately mapped out.

The *upper limit* of each *cerebral hemisphere* is indicated, approximately, by the median line at the top of the skull from the glabella to the external occipital protuberance, due allowance being made for the superior longitudinal sinus, which lies under the skull, in the longitudinal fissure, between the two hemispheres.

The *lower limit* is represented by a transverse line, in front, just above the upper margin of the orbit. At the side of the skull the line passes from about a half inch above the external angular process of the frontal bone to just above the external auditory meatus. From here it passes to the external occipital protuberance; this part of the line corresponding, approximately, to the lateral sinus. The cerebellum lies immediately below this line.

Of the brain fissures, those of greatest importance in cerebral localization are the Rolandic and Sylvian, since by means of these all the best known cortical centres can be located. Of the two, the *fissure of Rolando* is much the more important, because the motor, the most definitely known cortical area, is associated with it. Its upper limit is at a point about 12 mm. (one-half inch) behind the mid-point between the glabella and the inion, and about one-half inch from the median line. It passes outward, downward, and forward, approximately, at an angle of 71° with the median sagittal line of the skull. It is 8.5 cm. (3⅜ in.) long (Thane), and ends below just above the fissure of Sylvius. Near its lower end it turns rather suddenly downward, so that, in this part, it is not in the line of the angle of 71°.

Many methods have been devised for the purpose of making the line of the fissure on the scalp.

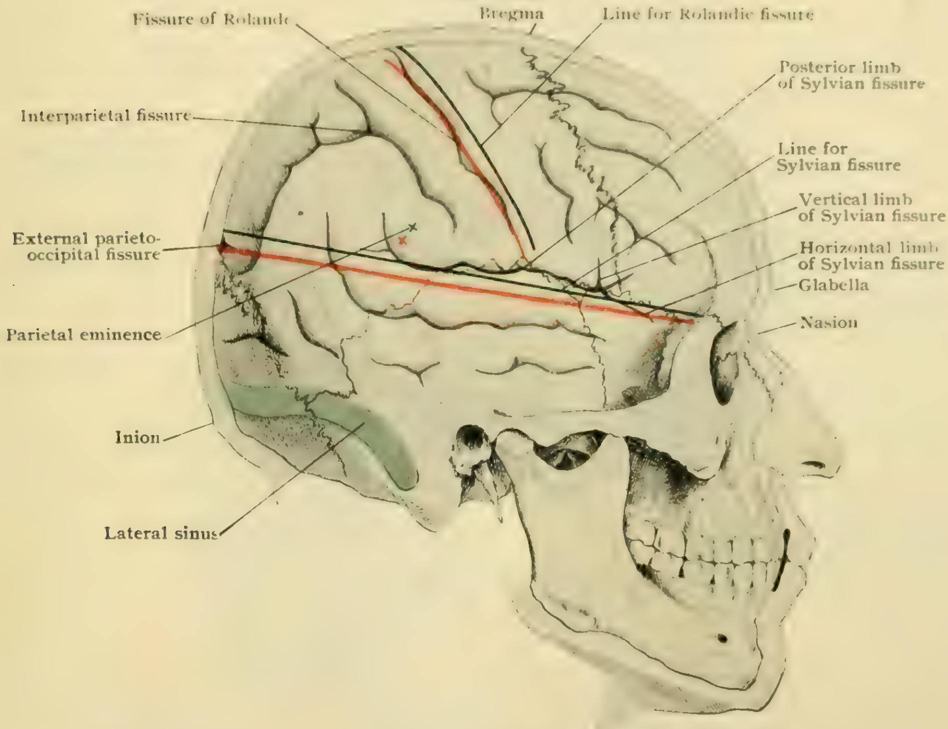
Chiene's method consists of folding an ordinary square sheet of paper on the diagonal line, thus dividing an angle of 90° in half, making two of 45°. One of these angles of 45° is again halved in a similar manner, making two new angles each of 22½°. The paper is then so unfolded that one of the angles of 22½° is added to that of 45°, making a new angle of 67½°; this will be sufficiently near that of the fissure of Rolando for all practical purposes.

Horsley's cyrtometer consists of two strips, either of thin, flexible metal or of parchment paper, each graduated in inches. The lateral arm is placed at an angle of 67° with the long arm, the apex of the angle being at a point 12 mm. or one-half inch behind the mid-point of the long arm.

Le Fort simply drew a line from the beginning of the fissure, above, to the middle of the zygoma, below, and marked off on this line the proper length of the fissure.

Anderson and Mackins suggest: (1) a median sagittal line from the glabella to the inion; (2) a frontal line from the mid-sagittal point to the depression just in front of the ear at the level of the upper border of the meatus; (3) a squamosal line from the most external point of the external angular process, at the level of the superior border of the orbit to the junction of the middle and lower thirds of the frontal line, and prolonged for about 3.7 cm. (1½ in.) behind the frontal line. The upper extremity of the central fissure was found by them to lie between the mid-sagittal point and a point 18 mm. (¾ in.) behind it, and the lower extremity of this fissure they located near the squamosal line, about 18 mm. (¾ in.) in front of its junction with the frontal line. The commencement of the lateral portion of the Sylvian fissure is not at a definite fixed point, but will usually be hit at a point from 3.7–5 cm. (1½–2 in.) behind the angular process, the course of the horizontal portion of this fissure corresponding closely to the squamosal line (Mills).

FIG. 1044.



Semidiagrammatic view of head, showing relation of Rolandic and Sylvian fissures and lines.

The *fissure of Sylvius* begins anteriorly, approximately, at a point 3 cm. (1¼ in.) behind the external angular process of the frontal bone; and ends posteriorly at a point 18 mm. (¾ in.) below the parietal eminence. A straight line between these two points will represent the fissure, which is about 10 cm. (4 in.) long. The anterior 18 mm. (¾ in.) of this line will correspond to the main portion of the fissure and the remainder to the horizontal limb. The vertical limb ascends for about 2.5 cm. (1 in.) from the posterior end of the main fissure. Around the posterior end of the horizontal limb, and approximately under the parietal eminence lies the supramarginal convolution. It is continuous in front with the ascending parietal convolution, and behind with the angular gyrus.

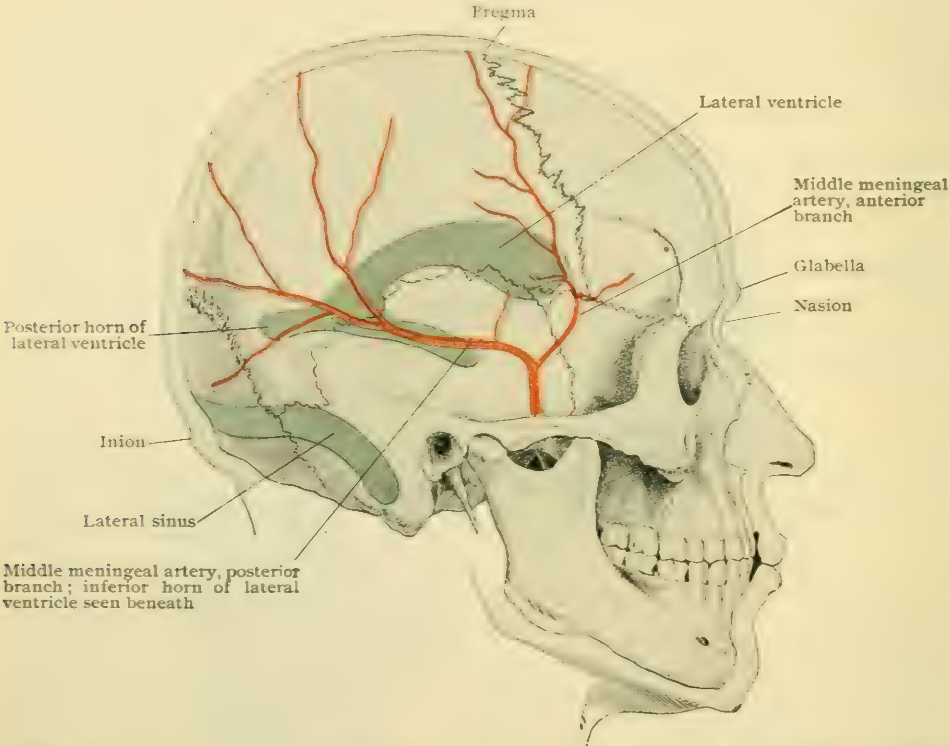
The *parieto-occipital fissure* is most marked on the mesial surface of the brain. The external limb passes outwards, almost at right angles to the longitudinal fissure on the external surface for about 2.5 cm. and lies from 2–3 mm. in front of the lambda.

The *frontal lobe* is divided into three main convolutions by the superior and inferior frontal sulci. The line for the superior frontal sulcus passes directly backward

from the supraorbital notch, and parallel to the longitudinal fissure to within 18 mm. (¾ in.) of the fissure of Rolando. The inferior frontal sulcus is represented, approximately, by the anterior end of the temporal ridge.

In the *parietal lobe* the most important sulcus is the intraparietal. It begins near the horizontal limb of the fissure of Sylvius, and passes upward and backward about midway between the fissure of Rolando and the parietal eminence. It then turns backward, running about midway to the longitudinal fissure and the centre of the parietal eminence. Above the sulcus, in front, lies the ascending parietal convolution, just posterior to the fissure of Rolando and behind the superior parietal lobule. Below the sulcus, anteriorly, is the supramarginal convolution, and posteriorly, the angular gyrus.

FIG. 1045.



Semidiagrammatic view of head, showing position of ventricles, lateral sinus and middle meningeal arteries as projected on skull.

The *temporal lobe* lies below the fissure of Sylvius and extends forward as far as the edge of the malar bone. The first temporal sulcus lies about one inch below and parallel with the fissure of Sylvius, and the second about 18 mm. (¾ in.) lower.

The *occipital lobe* lies posterior to the parieto-occipital fissure and the temporal lobe.

The motor tracts are made up of the fibres passing from the motor portion of the cortex in the Rolandic region to the motor nuclei from which arise the nerves supplying the muscles which the cortical areas control. After leaving the cortex the fibres pass downward in the corona radiata, and converge to the posterior limb of the internal capsule. The motor fibres of the cortico-bulbar and cortico-spinal tracts, occupy the genu and adjacent third of the internal capsule (page 1188), although Dejerine holds that the whole posterior limb is motor. They continue their course downward through the crura cerebri, pons, and medulla; in the lower part of the latter the greater number cross to the opposite side and pass down in the cord as the lateral or crossed pyramidal tract. A small number, sometimes absent, pass down

on the same side. We have already seen that lesions of the cortex produce monoplegia, unless large enough to involve the whole motor zone, but cortical hemiplegia is much more common than cortical monoplegia. In the internal capsule the motor fibres are gathered together so compactly that a small lesion, as an apoplectic hemorrhage, will frequently interrupt the whole tract and give a hemiplegia of the opposite side of the body.

In the medulla and cord the tracts of both sides are so close together that a lesion may easily paralyze both sides (paraplegia); indeed, diseases of the cord frequently involve the whole transverse section, paralyzing sensation as well as motion.

"Regarding disturbances of sensation, it is of importance to recall the anatomical relations of the chief sensory paths, the mesial fillet and the spino-thalamic tract. The former arises from cells within the gracile and cuneate nuclei of the medulla around which cells the long fibres of the posterior column end. The fibres of the fillet-tract, therefore, cross in the sensory decussation within the medulla. The fibres of the spino-thalamic tract, on the other hand, are axones of spinal cells situated on the opposite side and undergo crossing within the cord. Within the brain-stem, the two paths are closely associated and lesions within the medulla may involve both sets of fibres, leading to complete hemi-anesthesia of the opposite side. Unilateral lesions of the cord, on the contrary, produce only partial hemi-anesthesia, since within the cord the tracts ascend on different sides."

Hemiplegia is, therefore, the common form of cerebral paralysis; *paraplegia* the common form of spinal paralysis; while *monoplegia* occasionally results from lesions of the brain cortex, but more commonly from lesions of peripheral nerves.

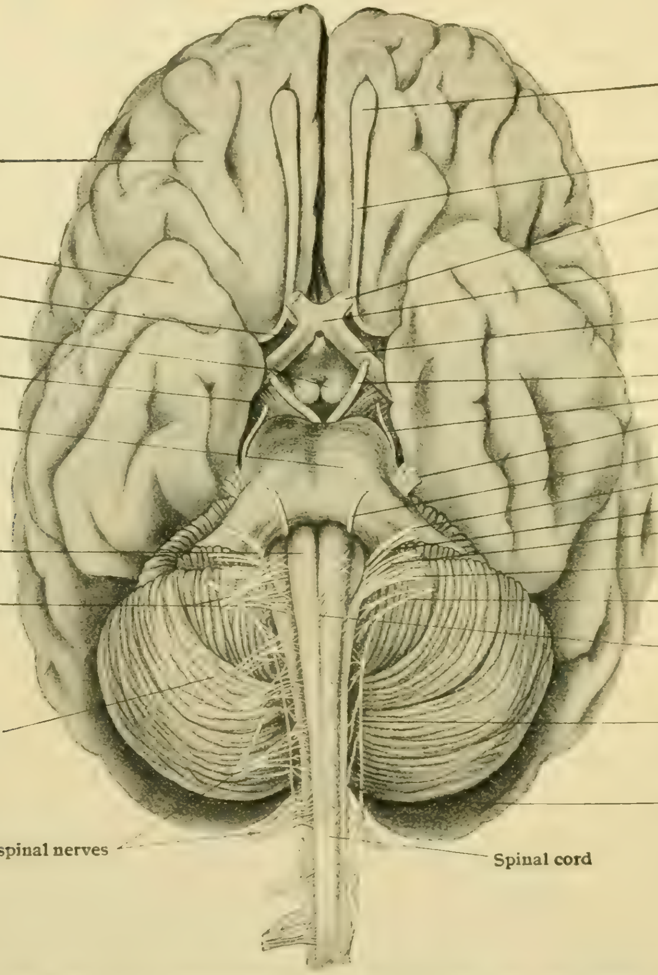
The sides and convexity of the brain can be exposed for operation, so that lesions of the cortex can be attacked and often removed; but the region of the internal capsule, which is near the basal ganglia, cannot be reached.

The soft brain may be injured by contact with its bony walls when the head is violently shaken, the spaces surrounding the brain and filled with fluid permitting considerable movement of the brain. The injury in cerebral contusion occurs more frequently on the under surface, both as regards the cerebrum and cerebellum, than on any other part (Prescott Hewett). That portion, however, which includes the medulla, pons, and interpeduncular space, rests on a large collection of cerebrospinal fluid, and is least frequently injured.

THE PERIPHERAL NERVOUS SYSTEM.

In a broad sense and as contrasted with the cerebro-spinal axis, the peripheral nervous system includes all the nerve-paths by which the various parts of the body are brought into relation with the brain and spinal cord. These paths embrace, in a general way, two groups. One group, the **somatic nerves,** includes the nerves

FIG. 1046.



Inferior aspect of brain, denuded of its membranes, showing superficial origins of cranial nerves ; origin of trochlear nerve is on dorsal surface and therefore not seen.

supplying the voluntary muscles, integument and organs of special sense ; the second group, the **visceral nerves,** includes those supplying the involuntary muscle throughout the body and the thoracic and abdominal viscera. The somatic nerves are subdivided into (*a*) the *cranial nerves*, which are attached to the brain and pass through foramina in the skull, and (*b*) the *spinal nerves*, which are attached to the spinal cord and traverse the intervertebral foramina. The visceral, or splanchnic

nerves, although directly or indirectly connected with the cerebro-spinal axis, present peculiarities and, as the *system of sympathetic nerves*, are accorded, at least for convenience of description, a certain degree of independence. While by no means all of the spinal nerves contribute splanchnic branches—such branches being given off especially by the thoracic and upper lumbar nerves—they all receive sympathetic filaments, which form, therefore, integral parts of the somatic nerves. From the sympathetic neurones of the gangliated cords axones pass, by way of the gray rami communicantes (page 1357), to the trunks of the spinal nerves and thence by these are carried to all parts of the body for the supply of the involuntary muscle occurring within the blood-vessels and the integument and for the cutaneous glands. Furthermore, it must be remembered, that although the predominating constituents of a spinal nerve may be axones derived from anterior horn root-cells and destined for voluntary muscle, such trunk also contains a number of afferent fibres which convey impulses received from the neuromuscular and neurotendinous sensory endings, the nerve-trunks reckoned as "motor" in all cases, when analyzed, being found to contain sensory and sympathetic fibres as well as efferent ones.

THE CRANIAL NERVES.

The cranial nerves (**nervi cerebrales**) include twelve pairs of symmetrically arranged nerve-trunks, which are attached to the brain and, traced peripherally, escape from the skull by passing through various foramina at its base to be distributed for the most part to the structures of the head.

The point at which a cranial nerve is attached to the surface of the brain is designated its **superficial origin**; the group of more or less deeply situated nerve-cells with which its fibres are directly related is often spoken of as its **deep origin.** From what has been said (page 1278) concerning the position of the cell-bodies of motor and sensory neurones, it is evident that only the motor fibres of the cranial nerves spring from nerve-cells within the cerebro-spinal axis, while the fibres conducting sensory impulses arise from nerve-cells situated within ganglia lying outside the central nervous axis and somewhere along the course of the nerve-trunks. It follows, therefore, that the term "deep origin," as applied to the cell-groups within the brain, can properly relate only to the origin of motor fibres; the cell-groups with which the sensory fibres come into relation after entering the brain-substance are in reality **nuclei of reception**, or of termination, and not of origin. The sensory impulses so received are transmitted to various parts of the brain by the more or less complex paths afforded by the neurones of the second, third, or even higher order. In addition to their relation to the deep nuclei, whether of origin or of reception, the fibres of every cerebro-spinal nerve are directly or indirectly influenced by neurones situated within the shell of gray matter that covers the cerebrum. The position of these higher **cortical centers,** as they are termed, is known with considerable accuracy for many groups of nerves, but regarding others more definite data concerning cerebral localization must be awaited.

Bearing in mind the foregoing distinctions, for convenience we may follow the conventional description in which all the nerves are regarded as passing away from the brain, the direction in which they convey impulses, centripetally or centrifugally, being for the time disregarded.

On leaving the surface of the brain at its superficial origin, each cranial nerve, invested by a sheath of pia mater, traverses for a longer or shorter distance the subarachnoid space, pierces the arachnoid and from the latter acquires an additional, but usually not extensive, sheath. It then enters a canal in the dura mater that leads to the foramen in the skull, through which the nerve escapes from the cranium, invested by a sheath prolonged from the dura which is continuous with the epineurium covering the nerve-trunk. The position of the dural aperture and that of the foramen by no means always correspond, some of the nerves, notably the fourth and sixth, pursuing an intradural course of some length before gaining their osseous exit.

According to the order in which they pass through the dura lining the cranium, the pairs of cranial nerves are designated numerically from the first to the twelfth. They are further distinguished by names based upon their distribution or functions.

Certain of the cranial nerves are entirely motor ; some convey the impulses of special sense ; while others transmit impulses of both common sensation and motion. A general comparison of these relations, as now usually accepted, is afforded by the following summary :

THE CRANIAL NERVES.

Number.	Name.	Function.
I.	OLFACTORY :	Special sense of smell.
II.	OPTIC :	Special sense of sight.
III.	OCULOMOTOR :	Motor to eye-muscles and levator palpebræ superioris.
IV.	TROCHLEAR :	Motor to superior oblique muscle.
V.	TRIGEMINAL :	Common sensation to structures of head. Motor to muscles of mastication.
VI.	ABDUCENT :	Motor to external rectus muscle.
VII.	FACIAL :	Motor to muscles of head (scalp and face) and neck (platysma). Probably secretory to submaxillary and sublingual glands. Sensory (taste) to anterior two-thirds of tongue.
VIII.	AUDITORY,	
	(*a*) Cochlear division :	Hearing.
	(*b*) Vestibular division :	Equilibration.
IX.	GLOSSO-PHARYNGEAL :	Special sense of taste. Common sensation to part of tongue and to pharynx and middle ear. Motor to some muscles of pharynx.
X.	PNEUMOGASTRIC OR VAGUS :	Common sensation to part of tongue, pharynx, œsophagus, stomach and respiratory organs. Motor (in conjunction with bulbar part of spinal accessory) to muscles of pharynx, œsophagus, stomach and intestine, and respiratory organs ; inhibitory impulses to heart.
XI.	SPINAL ACCESSORY :	Spinal Part : Motor to sterno-mastoid and trapezius muscles.
XII.	HYPOGLOSSAL :	Motor to muscles of tongue.

Practical Considerations.—Lesions may affect a cranial nerve within the brain or in its peripheral portion. A central lesion clinically is one above the nucleus of the nerve, and may be cortical or may encroach upon its intracerebral connections. It may merely irritate the nerve or may paralyze it. By a peripheral lesion is meant one involving the nucleus or the fibres of the nerve below the nucleus.

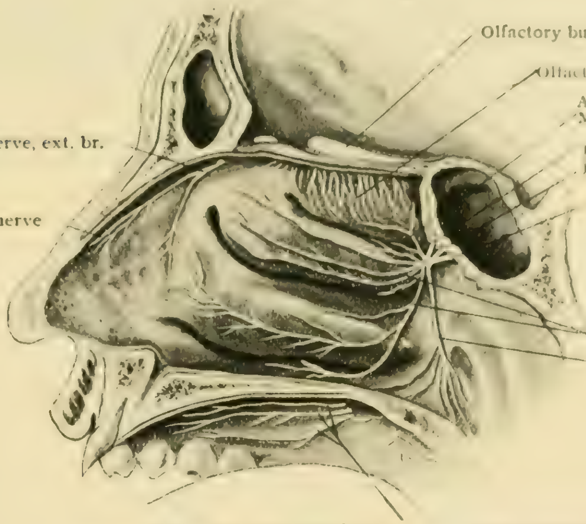
THE OLFACTORY NERVE.

The olfactory nerve (**n. olfactorius**), the first in the series of cranial nerves, presents some confusion in consequence of the name, as formerly employed, being applied to the olfactory bulb and tract as well as to the olfactory filaments—structures of widely diverse morphological values. As already pointed out (page 1151), the olfactory bulb and tract (Fig. 993), with its roots, represent, as rudimentary structures, the olfactory lobe possessed by animals in which the sense of smell is highly developed. It is evident that these structures, formerly regarded as parts of the first cranial nerve, are not morphological equivalents of simple paths of conduction. On the other hand such paths are represented by a series of minute filaments, the true olfactory nerves, that connect the perceptive elements within the nasal mucous membrane with the rudimentary olfactory lobe.

The **olfactory nerves proper,** some twenty in number, are the axones of the peripherally situated neurones, the *olfactory cells* (page 1414), which lie within the limited olfactory area. The latter embraces in extent on the outer nasal wall chiefly

the mesial surface of the superior turbinate bone and a somewhat larger field on the adjacent upper part of the nasal septum. The olfactory nerves (Fig. 1048),

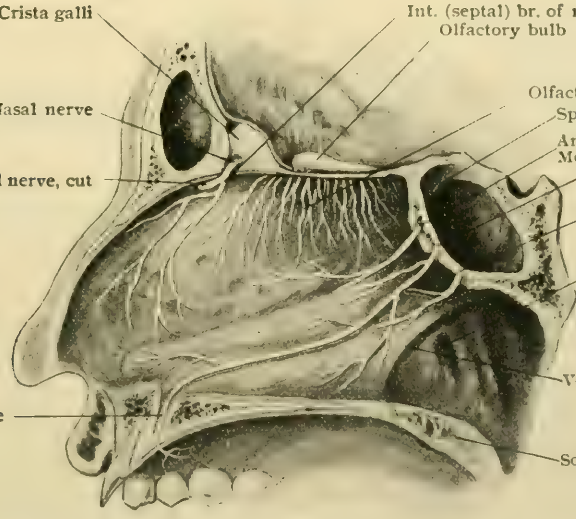
FIG. 1047.



Right nasal fossa showing distribution of olfactory and nasal nerves on lateral wall; mucous membrane has been partly removed to expose nerves.

whose fibres are nonmedullated, exhibit a plexiform arrangement within the deeper part of the nasal mucous membrane, pass upward through the cribriform plate of

FIG. 1048.



Right nasal fossa showing distribution of olfactory and nasal nerves on septal wall; mucous membrane has been partly removed to expose nerves.

the ethmoid bone and enter the under surface of the olfactory bulb. Within the latter the nerve-fibres end in terminal arborizations in relation with the dendritic processes of the mitral cells (Fig. 995), sharing in the production of the peculiar *olfactory glomeruli*.

Central and Cortical Connections.—The impulses conveyed by the olfactory nerves and received by the mitral cells of the olfactory bulb, which cells may be regarded as constituting the end-station or *reception-nucleus* of the peripheral path, are carried to neurones situated either within the gray matter of the olfactory tract, the anterior perforated space or the adjacent part of the septum lucidum (Fig. 1049). Fibres connecting the olfactory centres of the two sides proceed from the cortex of the tract by way of the anterior commissure, forming the *pars olfactoria* of the latter, to end in relation with the cells within the opposite tract or bulb. From these primary centres the impulses are transmitted by different paths to the secondary or *cortical centres* situated in the anterior part of the hippocampal convolution in the vicinity of its uncus, including the hippocampus major and the nucleus amygdalæ.

1. The most direct path is by way of the lateral root of the olfactory tract (page 1153), by which fibres from cells within the trigonum olfactorium pass, skirting the Sylvian fissure, to the anterior part of the gyrus hippocampi to terminate in relation with the cortical cells of that convolution.

FIG. 1049.

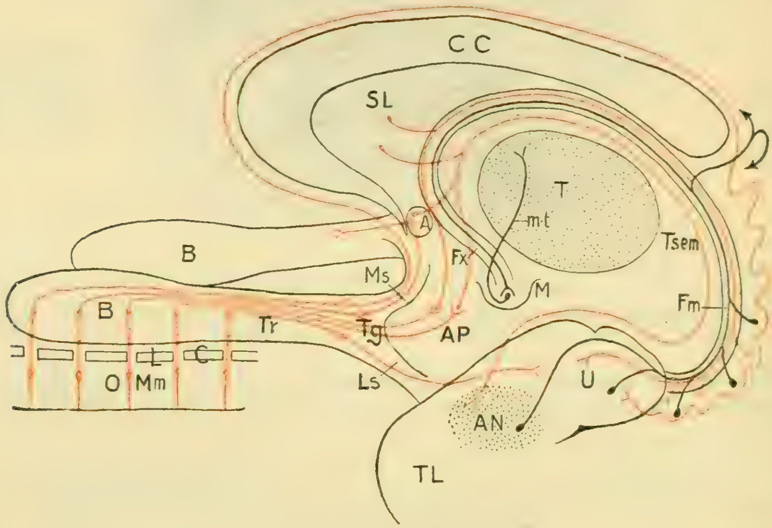


Diagram showing most important connections of olfactory tracts; *LC* lamina cribrosa; *B*, olfactory bulbs; *Tr*, olfactory tract; *Tg*, olfactory trigone; *Ls*, *Ms*, lateral and mesial striæ; *A*, anterior commissure; *CC*, corpus callosum; *SL*, septum lucidum; *Fx*, anterior pillar of fornix; *M*, mammillary body; *m-t*, mammillo-thalamic tract; *AP*, anterior perforated space; *Tsem*, tænia semicircularis; *T*, thalamus; *Fm*, fimbria descending on hippocampus; *U*, uncus; *AN*, amygdaloid nucleus; *TL*, temporal lobe.

2. Fibres from the cells within the olfactory trigone (page 1153) and the anterior perforated space (page 1153) pass into the septum lucidum and, reinforced by others from cells of the septum, enter the fornix; thence continuing backward and downward by way of the fimbria they reach the hippocampus major.

3. Fibres from cells within the olfactory trigone turn inward and by way of the medial root of the olfactory tract gain the gyrus subcallosus; thence they pass along the upper surface of the corpus callosum within its longitudinal striæ and descend by way of the dentate gyrus to reach the anterior end of the hippocampus major.

4. Fibres from cells within the anterior perforated space and septum lucidum, joined by accessions from the opposite olfactory tract by way of the anterior commissure, converge to the tænia semicircularis (page 1162) and, passing along the floor of the lateral ventricle, descend within the roof of the descending horn to end in the amygdaloid nucleus (Dejerine). During their ascent from the anterior perforated space, some fibres diverge almost at right angles and pass backward directly to the optic thalamus. The connections between the cortical centres of olfaction and the optic thalamus, as well as those between the olfactory centres of the two sides, by way of the fornix, are described on page 1167.

Practical Considerations.—Lesions of the uncinate gyrus may cause loss of the *sense of smell* on one or both sides. Paralysis of the *olfactory nerve* with loss of smell may also occur in fractures of the base of the skull in the anterior fossa, involving the cribriform plate.

THE OPTIC NERVE.

The optic nerve (**n. opticus**) is, as conventionally described, part of the pathway which includes additionally the optic commissure and the optic tract and transmits the visual impulses received by the retina to the primary centres within the pulvinar of the optic thalamus and the external geniculate and superior quadrigeminal bodies. The retina, the nervous tunic of the eye (page 1462), comprises three fundamental layers—(*a*) the percipient *visual cells*, (*b*) the receptive *ganglion retinæ* and (*c*) the *cerebral layer*. The latter contains the neurones, the axones of which constitute the nerve-fibres that converge towards the optic disc and, piercing the vascular and fibrous coats, form the greater part of the optic nerve, commissure and tract.

In addition to the fibres of retinal origin, which alone carry visual impulses, the optic nerve contains a considerable number of supplementary fibres, which are only indirectly concerned in sight. Some of these fibres, distinguished by their small diameter, pass toward the retina, originating within the brain from the cells of the primary visual centres or from sympathetic neurones, and probably transmit vasomotor impulses controlling the retinal blood-vessels. Other supplementary fibres, perhaps by way of a centre situated within the medulla, pass from the retina and are regarded as conveying indirectly to the oculomotor nucleus the impulses resulting in reflex pupillary movements.

The **optic nerve** (Fig. 1198) extends from the eyeball, which it leaves about 3 mm. to the medial side of the posterior pole, to the optic commissure. Leaving the eyeball, the nerve pursues a slightly sinuous course backward, inward and upward towards the apex of the orbit, where, surrounded by the origins of the recti muscles, it traverses the optic foramen in the sphenoid bone in company with the ophthalmic artery, which lies to its outer and lower side. On gaining the interior of the cranium, it converges towards the nerve of the opposite side with which it joins to form the major part of the *optic commissure* in the vicinity of the olivary eminence, medial to the internal carotid artery. The entire length of the optic nerve is from 30–40 mm., of which the intraorbital part includes from 20–30 mm., thus allowing for changes in the position of the eyeball without undue stretching of the nerve. Its diameter is from 3–4 mm. Within the orbit the nerve is embedded in the orbital fat and surrounded by the ocular muscles and, near the eyeball, by the ciliary vessels and nerves. It is crossed above and from without inward by the ophthalmic artery and the nasal nerve, and, about 10 mm. from the eyeball, is penetrated by the central artery of the retina, which, with its companion vein, continues its intraneural course as far as the optic disc. In addition to a sheath from the pia mater and a delicate one from the arachnoid, the optic nerve receives a robust tubular prolongation from the dura at the optic foramen. These sheaths, with the intervening subarachnoidal and subdural lymph-spaces, are continued on the nerve as far as the eyeball, where they blend with the sclerotic coat.

The **optic commissure** (Fig. 1046), formed by the meeting of the converging optic nerves in front and the diverging optic tracts behind, is somewhat flattened and transversely oblong and measures about 12 mm. where broadest. It rests upon the olivary eminence, is embraced at the sides by the internal carotid arteries, and lies beneath the floor of the third ventricle in advance of the tuber cinereum in close relation with the inferior surface of the brain. It divides posteriorly into the two optic tracts. On reaching the commissure, or *chiasm*, as it is sometimes called, the optic fibres, estimated at upwards of half a million (Salzer), undergo partial decussation, those from the nasal or inner half of each retina crossing to the mesial part of the opposite optic tract, while those from the temporal or outer half continue into the lateral part of the tract of the same side. The existence of a commissural loop connecting the two optic nerves has not been established, although formerly accepted.

Occasional instances have been encountered in which the decussation of the optic fibres was complete, thus repeating in man the condition that normally obtains in all nonmammalian vertebrates, as well as in a few rodents (mouse, guinea-pig). Rarely the optic commissure has been absent, the optic fibres passing directly into the tract of the same side.

The entire commissure, however, is not composed of optic fibres, since its posterior part is formed by a bundle, known as **Gudden's commissure** (**commissura inferior**) (page 1110), which passes forward along the mesial side of the optic tract, loops around the posterior angle of the commissure and enters the opposite tract. These fibres have no connection with the path of sight-impulses, but are probably chiefly related with the median or internal geniculate bodies and the inferior corpora quadrigemina (page 1110).

The optic commissure also contains fibre-strands that arch around its posterior angle, parallel with, but separated by a thin layer of gray matter from Gudden's tract. Concerning the origin and destination of these fibres, termed **Meynert's commissure** (**commissura superior**), little is known. By some they are regarded as continuations of the mesial fillet that, after decussation, pass to the globus pallidus of the lenticular nucleus of the opposite side. Others deny such relations, while Kölliker describes them as bending upward, traversing the ventral part of the cerebral peduncle, to end within the corpus subthalamicum (page 1128).

FIG. 1050.

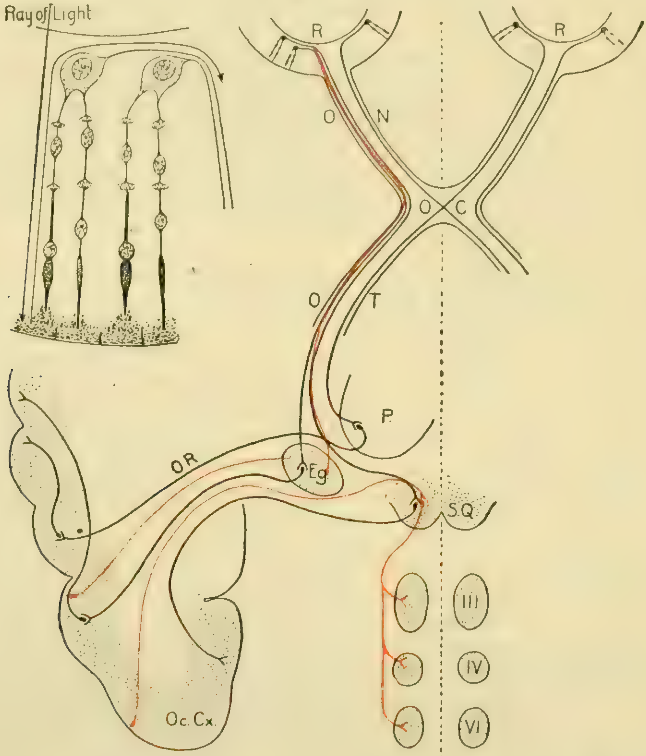


Diagram showing course of retinal fibres in optic pathway and their connection with basal ganglia and primary cortical centres; smaller figure illustrates path of light-ray and resulting impulse through retina: *R*, retina: *ON*, *OC*, *OT*, *OR*, optic nerve, chiasm, tract and radiation. *P*, pulvinar; *Eg*, *SQ*, lateral geniculate and superior quadrigeminal bodies; *Oc Cx*, occipital cortex; *III*, *IV*, *VI*, nuclei of eye-muscle nerves.

Additional commissural fibres (**commissura ansata**) descend from the floor of the third ventricle and from the peduncle of the septum lucidum, by way of the lamina terminalis, to the front and upper part of the optic chiasm; other fibres pass from the ventricular floor to the back of the chiasm. For the most part these fibres cross to the opposite side to be lost in the substance of the optic commissure. Although regarded as in a way constituting a *ventral optic root*, their connections and significance are not understood.

The **optic tract** (Fig. 993) is the continuation of the optic nerve, its chief constituents being the crossed and uncrossed retinal and the supplementary fibres. On leaving the commissure, the tract diverges in front of the interpeduncular space, mesial to the anterior perforated space and the termination of the internal carotid artery, and sweeps outward and backward from the base of the brain around and close to the cerebral peduncle, becoming flatter and broader as it proceeds. Near

its posterior end the tract exhibits a furrow that indicates a subdivision into a *mesial* and a *lateral root* (Fig. 915). The latter, the visual portion of the optic tract, is traceable into the prominent overhanging pulvinar of the optic thalamus, the ill-defined lateral geniculate body and, by means of the superior brachium, into the superior quadrigeminal body. The mesial root, on the other hand, contains the fibres forming Gudden's commissure (page 1110) and is related to the distinct median geniculate body and, by the inferior brachium, to the inferior quadrigeminal body.

Central and Cortical Connections.—Arising as axones of the retinal neurones, the optic nerve-fibres are continued backward through the commissure and tract and end in relation with the neurones of the primary centres situated in the pulvinar, the lateral geniculate and the superior quadrigeminal body. It is, however, within the lateral geniculate body that the greater number (80 per cent. according to Monakow) of the visual fibres terminate, relatively few passing to the pulvinar and the superior quadrigeminal body (Spiller). The **cortical connections** are established by fibres which pass from the cells of these primary centres and, as the *optic radiation* (page 1123), sweep outward and backward into the occipital lobe to end in the cortex of the cuneus in the vicinity of the calcarine fissure. It is probable that a limited number of retinal fibres pass directly to the cerebral cortex without interruption in the primary centres. In addition to the centripetal paths just mentioned, fibres arise from the cortical cells of the cuneus and, sharing the optic radiation, pass as efferent tracts which not only terminate in the lateral geniculate and quadrigeminal bodies, but also establish indirect relations with the nucleus of the oculomotor nerve. The ultimate distribution and influence of the impressions of sight are very complex and far reaching, such impressions being capable of affecting numerous motor and sensory centres.

The exact path by which pupillary impulses reach the oculomotor nucleus is uncertain and perhaps two-fold. It may be assumed, however, that if they proceed by way of the superior quadrigeminal body, the optic fibres are not directly continued to the nucleus of the third nerve, but end within the superior colliculus, from whose neurones the immediate connecting links proceed to the oculomotor nucleus. Accumulating evidence points to the existence of a more remote special centre for pupillary reflexes within the lower part of the medulla ; in such case the oculomotor nucleus is, perhaps, influenced by impulses which pass from the medullary centre upward by way of the posterior longitudinal fasciculus (Bach).

Practical Considerations.—The cranial nerves of the *eye* will be discussed in connection with that organ.

THE OCULOMOTOR NERVE.

The third or oculomotor nerve (**n. oculomotorius**), the chief motor nerve of the intrinsic and extrinsic muscles of the eyeball, supplies branches to all the extraocular muscles, with the exception of the external rectus and superior oblique, as well as fibres to the sphincter pupillæ and the ciliary muscle within the eyeball.

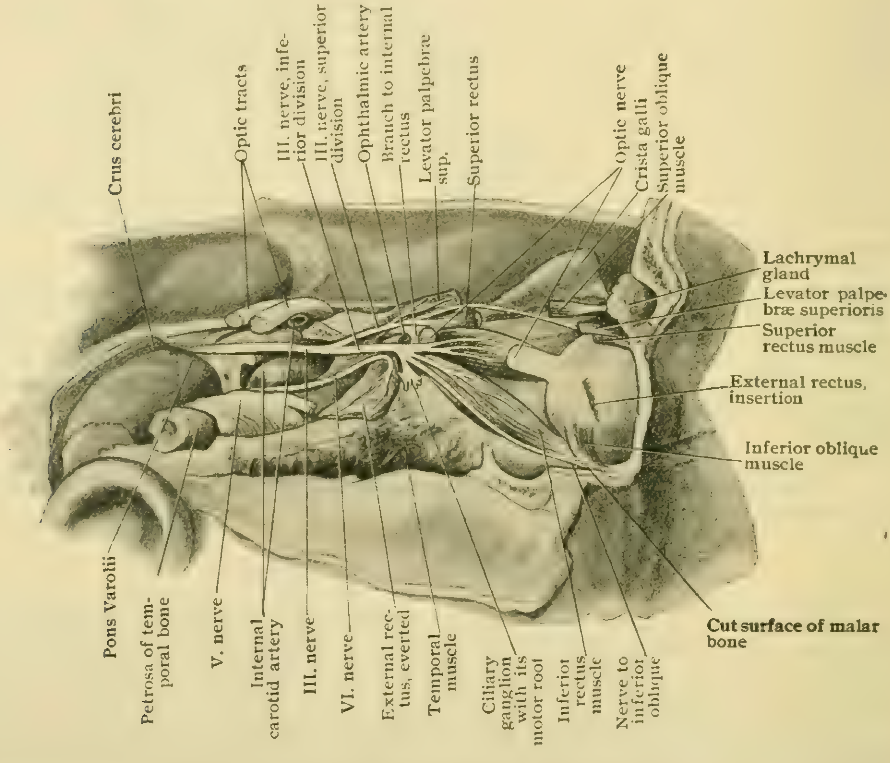
Its **deep origin** is from the *oculomotor nucleus* situated medially and deeply within the gray matter of the floor of the Sylvian aqueduct, in close relation with the dorsal surface of the posterior longitudinal fasciculus (Fig. 963).

The nucleus is from 6–8 mm. in length and extends from opposite the upper end to the caudal pole of the superior quadrigeminal bodies. Below, its posterior end comes almost into contact with the nucleus of the fourth nerve, but is separated from it by a narrow interval. In its entirety the oculomotor nucleus includes a number of more or less distinct cell-groups, which vary in importance as well as in their individual prominence. Of these the most important and constant are two long columns of cells, the **chief nuclei**, that extend, one on each side, along the dorsal surface of the posterior longitudinal fasciculi. Each nucleus tapers slightly towards either end and consists of two fairly distinct subdivisions which, from their relative positions, are termed the *dorsal* and the *ventral cell-group*. The component nerve-cells include those of large, medium and small size, the large multipolar ones (from .040–.045 mm. in diameter) probably being the elements from which the root-fibres of the third nerve arise. Dislocated portions of the chief nucleus are seen as small groups of nerve-cells that lie scattered among or even beneath the fibres of the posterior longitudinal bundle.

Dorsal to the chief nucleus and partially overlying its postero-median surface is the tapering column of small nerve-cells known as the **Edinger-Westphal nucleus**. This tract, much more bulky above than below (Tsuchida), exhibits a subdivision into a dorso-lateral and a ventro-median portion, which, however, are fused in the superior pole of the nucleus. The

exact relations of the Edinger-Westphal nucleus to the fibres of the third nerve are still undetermined, and, indeed, even its close association with these has been questioned. The assumed importance of the nucleus as a centre for pupillary reflexes (Bernheimer) has been seriously shaken by the recent observations of Tsuchida.[1] This investigator also denies the existence of a well marked and constant unpaired median nucleus as described by Perlia, but admits the presence of broken groups of medially placed cells, especially in the upper and lower thirds of the nucleus. The lateral group of cells, beginning in the floor of the third ventricle and extending caudally as far as the upper third of the chief nucleus, constitutes the **nucleus of Darkschewitsch.** Notwithstanding its proximity to the origin of the third nerve, this nucleus is now regarded as having no direct relation with that of the oculomotor, but as standing in intimate association with the posterior longitudinal bundle, among whose fibres the cells to a large extent lie; it is, therefore, now often referred to as the **nucleus fasciculi longitudinalis posterioris.**

FIG. 1051.



Dissection of right orbit, showing oculomotor and abducent nerves.

Although it may be assumed with much probability that the fibres destined for the different eye-muscles originate from definite groups of nerve-cells, all attempts to locate with accuracy the position of such centres within the oculomotor nucleus have met with only partial success. Tsuchida's conclusions, based upon histological, embryological, comparative and clinical data, point to an unexpected diffuseness in the origin of the oculomotor fibres with only a limited relation to distinct groups.

Concerning the mooted question as to the extent of decussation of the oculomotor fibres it seems probable that such crossing occurs principally within the caudal portion of the chief nuclei, although, according to Tsuchida and others, some decussating fibres are found throughout the greater part of the nuclei.

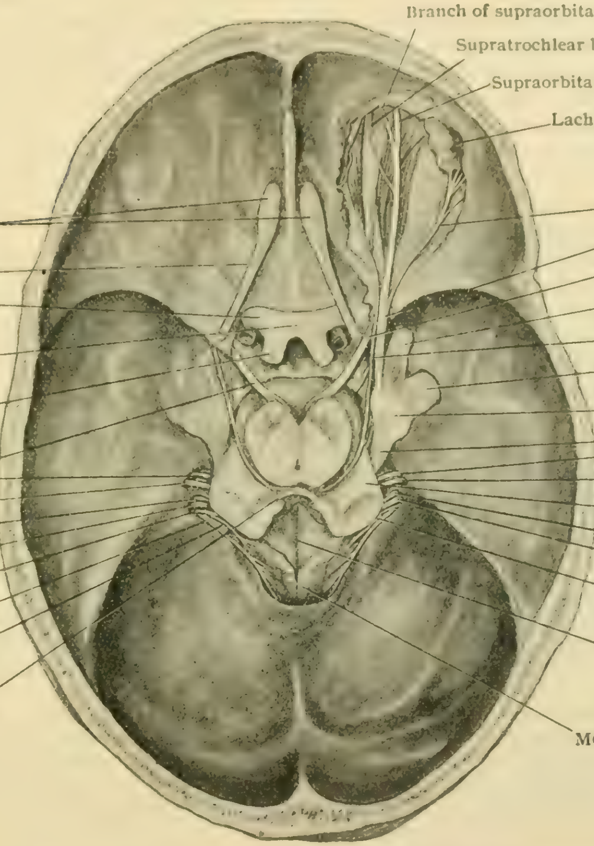
The fibres of the third nerve originate principally as the axones of the cells on the same side, although a small number are derived from the neurones lying on the opposite side of the mid-line. Some of these decussating fibres supply the internal rectus and are related with the nucleus of the sixth nerve, which sends fibres by way of the posterior longitudinal bundle into the oculomotor nucleus. Whether these

[1] Arbeiten a. d. Hirnanatom. Institut in Zürich, Heft ii., 1906.

fibres end within the latter nucleus around the cells from which the decussating fibres proceed, or are actually prolonged as certain of the decussating fibres is uncertain; their purpose is to bring into coordinated action the internal rectus of one side with the opposite external rectus when the two eyes are directed laterally, as in conjugate deviation.

Cortical and Central Connections.—As in the case of all other motor cranial nerves, the nucleus of the third nerve stands in direct relation to the cerebral cortex. Fibres from the cells of the cortical centre—axones from the neurones within the posterior part

FIG. 1052.



Base of skull, viewed from above, showing cranial nerves passing through dura; roof of right orbit has been removed to expose the ophthalmic nerve.

of the inferior frontal convolution, slightly in front of the precentral fissure (Mills)—proceed by way of the corona radiata, the internal capsule and the cerebral peduncle to the oculomotor nucleus, around whose cells, chiefly but not exclusively on the opposite side, they end. Other connections of the nucleus of the third nerve include: (1) indirectly with the cortical visual area by fibres that pass from the occipital cortex through the optic radiation and superior brachium to the superior corpora quadrigemina; (2) indirectly with the visual centres by fibres that descend from the cells within the superior corpora quadrigemina; (3) by means of the posterior longitudinal bundle with the nuclei of the other ocular nerves (the fourth and the sixth) and also with the vestibular (Deiters') nucleus of the eighth; (4) with the facial nucleus by fibres that descend from the oculomotor nucleus along the posterior longitudinal bundle to the cells from which proceed the fibres supplying the orbicularis palpebrarum and the corrugator supercilii muscles, which are thus brought into coördinated action with the levator palpebrarum.

Intracranial Course.—Leaving their deep origin as the axones of the nuclear cells, the oculomotor fibres sweep in ventrally directed curves (Fig. 963) through the posterior longitudinal bundle, tegmentum, red nucleus and inner margin of the substantia nigra and, collected into about a dozen root-bundles, have their **superficial origin** along a shallow groove, the *oculomotor sulcus* (Fig. 974), on the medial surface of the cerebral peduncle, just in front of the pons and at the side of the interpeduncular space.

Beyond this superficial origin, the linear group of root-fibres soon becomes consolidated into the large and conspicuous trunk of the third nerve, although not infrequently one root-bundle emerges more laterally from the ventral surface of the cerebral peduncle and for a short distance remains separated from the other constituents. The nerve courses forward and outward from the posterior perforated space, between the posterior cerebral and superior cerebellar arteries, to the outer side of the posterior clinoid process, where, in the triangular interval between the free and attached borders of the tentorium, it enters the dura (Fig. 1033). Embedded within this membrane, the nerve follows the upper portion of the outer wall of the cavernous sinus and leaves the cranium by entering the orbit through the sphenoidal fissure. On gaining the median end of the fissure the nerve divides into a *superior* and an *inferior branch*, which enter the orbit by passing between the two heads of the external rectus muscle, in company with, but separated by, the nasal branch of the trigeminal nerve, the sixth nerve lying below.

Branches and Distribution.—The **superior branch** (**ramus superior**) (Fig. 1051), the smaller of the two, passes upward, over the optic nerve, to the superior rectus muscle, which, together with the levator palpebræ superioris, it supplies. In both cases the nerve enters the ocular surface of the muscle.

The **inferior branch** (**ramus inferior**) (Fig. 1051) is directed forward and, after giving off twigs to the ocular surface of the internal and inferior recti, is continued below the eyeball, between the inferior and external straight muscles, to supply the inferior oblique, whose posterior border it enters. This, the longest branch of the oculomotor nerve, in addition to sending one or two fine twigs to the inferior rectus, contributes a short thick *ganglionic branch* (Fig. 1051), which joins the postero-inferior part of the ciliary ganglion (page 1236) as its short or motor root and conveys fibres destined for the sphincter pupillæ and ciliary muscles. Sensory fibres from the ophthalmic division of the fifth nerve are distributed to the muscles along with the fibres of the third, having joined the latter before it entered the orbit. Similarly in the wall of the cavernous sinus, the nerve is joined by sympathetic fibres from the cavernous plexus on the internal carotid artery.

Variations.—These consist, for the most part, of unusual branches which at times seemingly replace one of the other motor orbital nerves. Thus, the third nerve may give a branch to the external rectus, either in addition to, or to the exclusion of the sixth, which may be absent; or it may give a filament to the superior oblique. Minor deviations in the course of its branches, such as piercing the inferior rectus or the ciliary ganglion, have also been recorded.

THE TROCHLEAR NERVE.

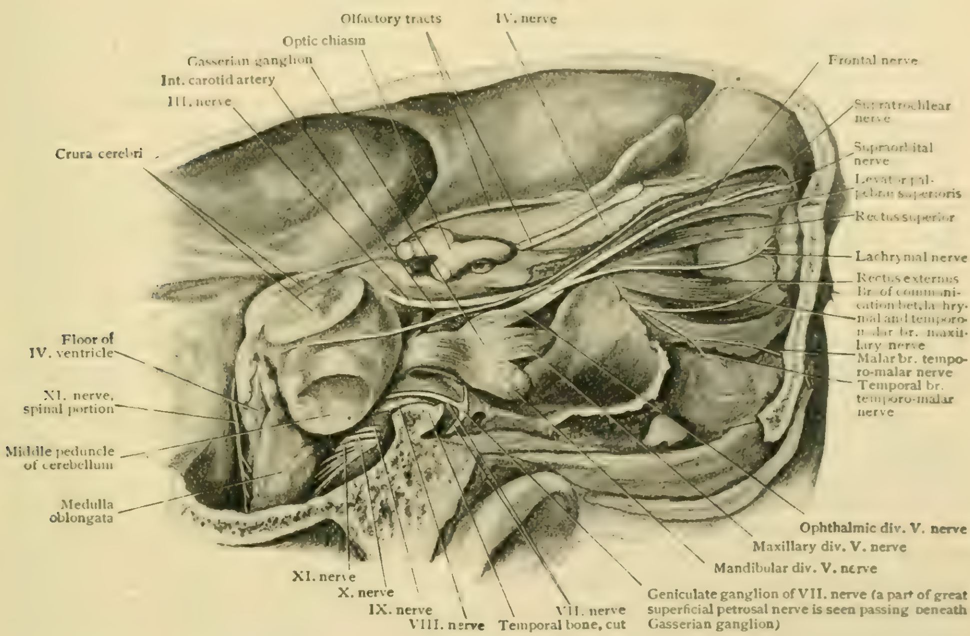
The fourth or trochlear nerve (**n. trochlearis**), also called the *pathetic*, is the smallest of the cranial series and supplies the superior oblique muscle of the eyeball. The **deep origin** of the nerve is from the *trochlear nucleus*, a small oval collection of cells situated in the ventral part of the gray matter surrounding the Sylvian aqueduct, that extends from opposite the upper part of the inferior quadrigeminal body to the lower pole of the superior colliculus. This nucleus, about 2 mm. in length, lies near the mid-line and immediately below (caudal to) that of the third nerve, from which, however, it is distinct, being separated by a narrow interval from the ventral part of the oculomotor nucleus. It lies in intimate relation with the posterior longitudinal fasciculus in a distinct depression on the dorsal surface of that bundle (Fig. 960). In structure the trochlear nucleus resembles that of the oculomotor, its nerve-cells including those of large, medium and small size.

Arising from the nucleus, the root-fibres of the fourth nerve pursue a course of considerable length within the mid-brain before gaining their superficial origin.

Leaving the upper and lateral part of the nucleus as axones of the trochlear neurones, the strands of fibres pass outward and backward within the gray matter of the floor of the aqueduct until they near the inner concave surface of the mesencephalic root of the fifth nerve, which, after being condensed into one or two bundles, they follow downward as far as the superior extremity of the fourth ventricle. Then bending sharply medially, the fourth nerve, so far as the great majority of its fibres are concerned, enters the superior medullary velum, in which it decussates with its fellow of the opposite side and crosses the mid-line to emerge at its **superficial origin** on the dorsal surface of the brain-stem (Fig. 957) just below the inferior corpora quadrigemina, between the frenum of the velum and the mesial border of the superior cerebellar peduncle.

Cortical and Central Connections.—The trochlear nucleus is directly connected with the cerebral cortex by fibres which descend from the inferior frontal convolution through the corona radiata, the internal capsule and the cerebral peduncle and cross to the nucleus of the opposite

Fig. 1053.



Dissection showing right trochlear nerve throughout its length, also oculomotor and frontal and lachrymal branches of trigeminal nerve; roof and outer wall of orbit have been removed.

side. By means of the posterior longitudinal bundle it is brought into relation with the nucleus of the third and of the sixth nerve, thus insuring harmonious action of the eye muscles; further, by means of the same path, it is probably connected with the auditory nuclei by way of the superior olive and its peduncle.

Course and Distribution.—Emerging at its superficial origin, the nerve is directed outward over the superior cerebellar peduncle, then winds forward around the outer surface of the cerebral peduncle, parallel to and between the posterior cerebral and superior cerebellar arteries, and appears at the base of the brain (Fig. 1053). Proceeding forward to the floor of the cranium, the nerve enters the dura immediately beneath the free border of the tentorium, slightly behind and external to the posterior clinoid process and the third nerve, and continues in the outer wall of the cavernous sinus, at first having the third nerve above it and the ophthalmic division of the fifth below, and then crossing above the third from below inward, to gain the medial end of the sphenoidal fissure. It enters the orbit above the heads of

the external rectus muscle and, directed medially, crosses above the levator palpebræ superioris and superior rectus and reaches the superior oblique, which it enters on the upper surface close to the external border (Fig. 1056).

The **communications** of the trochlear nerve, as it courses in the wall of the cavernous sinus are: (1) filaments from the carotid sympathetic plexus; (2) fibres of common sensation from the ophthalmic division of the fifth.

Variations.—The course of the trochlear nerve is sometimes through instead of over the levator palpebræ superioris. Unusual branches to sensory nerves, as the frontal, supratrochlear, the infratrochlear and the nasal, are probably due to the aberrant course of sensory fibres from the trifacial. The fourth nerve occasionally sends a branch to the orbicularis palpebrarum.

THE TRIGEMINAL NERVE.

The fifth, trigeminal or trifacial nerve (**n. trigeminus**), the largest of the cranial series, is a mixed nerve and consists of a large *sensory part* (**portio major**) and a much smaller *motor portion* (**portio minor**). The former supplies fibres of common sensation to the front part of the head, the face, a portion of the external ear, the eye, the nose, the palate, the naso-pharynx in part, the tonsil, the mouth and the tongue. The motor portion is distributed to the muscles of mastication, the mylohyoid and the anterior belly of the digastric. The relation of the fibres composing these two parts to the cells within the brain-stem is, therefore, very different, in the case of the motor fibres the cells being a nucleus of origin and in that of the sensory fibres one of reception.

The Sensory Part.—The fibres comprising the sensory part of the trigeminal nerve, which convey sensory impulses from the various head-structures, are the processes of cells lying outside the central axis in the Gasserian ganglion on the sensory root. The portions of the fibres between the periphery and the ganglion correspond to elongated dendrites, while the much shorter centrally directed constituents of the sensory root, connecting the ganglion with the brain-stem, are the axones of the Gasserian neurones. The general resemblance between the fifth cranial nerve and a typical spinal nerve is striking, in each case the sensory root bearing a ganglion and the motor root proceeding from cells within the central nervous axis.

Proceeding brainward as axones of the Gasserian cells, the sensory fibres of the trigeminal nerve become consolidated into the large sensory root, which passes through an opening in the dura mater (Fig. 1033) situated beneath the attachment of the tentorium cerebelli to the posterior clinoid process. Coursing backward through the posterior fossa of the cranium it enters the brain-stem on the lateral surface of the pons, slightly behind the superior border, as the conspicuous group of robust bundles that mark the **superficial origin** of the nerve (Fig. 1046). Just above it is the superficial origin of the motor root, from which it is separated by a small bundle of pontine fibres which belong to the middle cerebellar peduncle. Below and in line with it are the superficial origins of the facial and auditory nerves.

Entering the tegmental portion of the pons, close to the overlying superior cerebellar peduncle, the sensory fibres soon come into relation with the extensive **trigeminal reception-nucleus**, a columnar mass of gray matter within the lateral part of the tegmentum (Fig. 935). This nucleus extends from the middle of the pons through the entire length of the medulla and into the spinal cord as far down as the level of the second cervical segment, where it becomes continuous with the substantia gelatinosa of the cord. The rounded and enlarged upper end of this tapering column is described as the **sensory nucleus** of the fifth nerve, although it comprises only a small part of the reception-nucleus. The latter, in turn, is the upward prolongation of the **substantia gelatinosa Rolandi**, conspicuous in all cross-sections of the lower pons and medulla as an oval field of gray matter (Fig. 930).

On nearing this column the sensory fibres divide into ascending and descending branches, much in the same way as the posterior root-fibres bifurcate within the posterior columns of the cord. The ascending fibres, distinctly finer than the descending, soon penetrate the sensory nucleus and the substantia gelatinosa and end in arborizations around the neurones of the reception nucleus. The coarser descending fibres become collected into a compact bundle, the descending or **spinal root** (**tractus spinalis n. trigemini**), whose medially directed concavity closely embraces the lateral surface of the column of gray substance. Beginning with its descent, the

spinal root gives off collaterals and fibres that bend medially, enter the adjacent substantia gelatinosa and end in arborizations around the reception cells of that nucleus. Since the number of fibres is thus progressively reduced during the descent of the spinal root, the tract is tapering, becoming smaller and smaller as it approaches the spinal cord until within the upper part of the latter, at about the level of the second cervical nerve, it finally disappears. In its descent through the brain-stem the spinal tract becomes more and more superficially placed, in the lower part of the pons lying to the inner side of the restiform body, separated from it by the vestibular division of the auditory nerve, and lower, in the lateral area of the medulla, occupying a position close to the surface as it rests upon the expanded gelatinous substance of the tuberculum Rolandi.

The **central connections of the sensory part** of the trigeminus (Fig. 1054), by way either of the collaterals of the fibres of the spinal root or of the axones and collaterals of the axones of the reception neurones, are undoubtedly very extensive, since the impulses collected by this important nerve are widely dispersed. The most important paths for such distributions are:

1. By axones that pass, as arcuate fibres, from the cells of the reception-nucleus across the raphe to join the opposite mesial fillet and ascend to the optic thalamus and thence, after interruption in the cells of the latter, by axones of thalamic neurones to the cerebral cortex. It is probable that some of the arcuate fibres do not cross the mid-line, but ascend within the mesial fillet of the same side. It is also probable that collaterals of the arcuate fibres pass to the trigeminal, facial and glosso-pharyngeo-vagal motor nuclei.

2. By axones from the cells of the reception nucleus that enter the inferior cerebellar peduncle of the same side and pass to the cerebellar cortex as constituents of the *nucleo-cerebellar tract.*

3. By collaterals that are distributed to the nuclei of origin of the hypoglossal and of the motor part of the trigeminus and facial nerves, whereby these important motor nerves are brought directly under the influence of the sensory part of the fifth.

FIG. 1054.

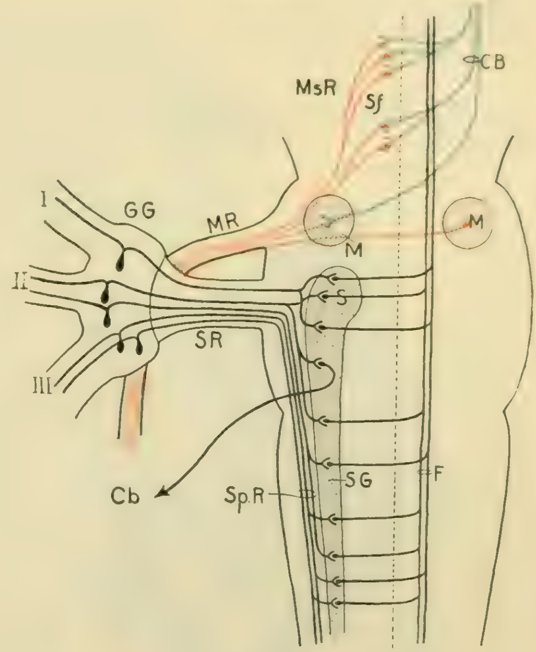


Diagram showing relations of trigeminal root-fibres to nuclei within brain-stem; *GG*, Gasserian ganglion with divisions (*I, II, III*) of sensory part of nerve; *SR*, *MR*, sensory and motor roots; *S*, sensory nucleus; *SG*, substantia gelatinosa; *Sp.R*, spinal or descending root; *F*, mesial fillet; *Cb*, nucleo-cerebellar fibre; *M*, motor nucleus; *MsR*, mesencephalic root; *Sf*, substantia ferruginea; *CB*, cortico-bulbar fibres.

The Motor Part.—In contrast to the median position of the nuclei of origin of the oculomotor, trochlear, abducent and hypoglossal nerves, the **deep origin** of the motor part of the trigeminus includes groups of cells that lie at some distance from the raphe and fall into series with the laterally placed nuclei of the motor parts of the other mixed cranial nerves—the facial, the glosso-pharyngeal and the vagus.

1. The largest contingent of the motor fibres of the trifacial nerve arise as axones from the neurones within the **chief motor nucleus** (**nucleus masticatorius**) (Fig. 935). This nucleus consists of a short columnar collection of gray matter, oval on cross-section, which lies in the upper part of the pons, close to the median side of the sensory nucleus. It is composed of large stellate cells from which, as their axones, the motor fibres proceed outward through the tegmentum to their superficial origin on the pons. A small number of fibres, from the more medially situated cells of the nucleus, pursue a dorsally convex course toward the raphe, which they cross close beneath the floor of the fourth ventricle to join the motor nucleus of the opposite side and become incorporated in the opposite trigeminal motor root.

2. A second and smaller constituent of the motor root, the descending **mesencephalic root** (**radix descendens n. trigemini**) includes fibres that arise from cells lying within the lateral part of the gray matter surrounding the Sylvian aqueduct. In cross-sections (Fig. 936) this root appears as a delicate crescentic bundle that descends from the mid-brain to join the larger tract

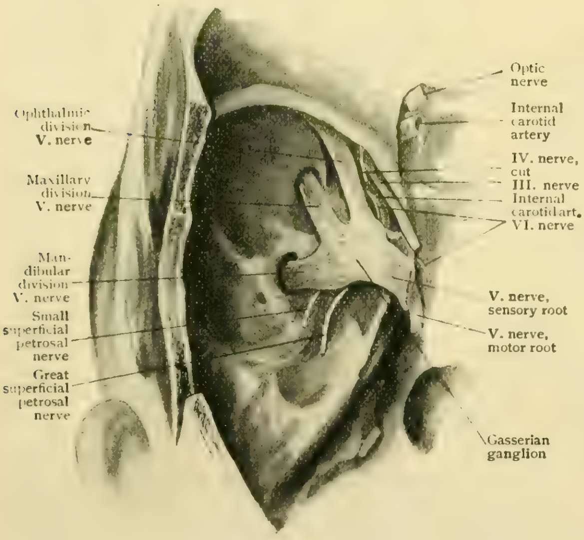
of fibres from the chief motor nucleus. In its downward course the mesencephalic root is joined by numerous fibres which have their origin in the pigmented cells of the substantia ferruginea (page 1081) of the same and, possibly, of the opposite side.

The fibres from these various sources—the mesencephalic nucleus, the substantia ferruginea and the motor nucleus—become consolidated into the motor root of the trigeminal nerve, whose **superficial origin** (Fig. 1046) is just above that of the sensory root, from which it is separated by some of the superficial transverse fibres of the pons. Leaving the side of the pons, the motor root follows the same course to and through the dura mater as does the sensory, to the inner side of which it lies. It eventually passes beneath the Gasserian ganglion to become exclusively an integral portion of the mandibular division of the trigeminal.

The **cortical connections of the motor root** are established by fibres that arise from cells within the cortical gray matter of the lower third of the precentral convolution. Thence, as constituents of the pyramidal tracts, they descend through the corona radiata, the internal capsule and the cerebral peduncle into the pons, where, for the most part after decussation, they terminate in end-arborizations around the radicular cells of the motor trigeminal nuclei.

The Gasserian Ganglion.—The Gasserian ganglion (**ganglion semilunare [Gasseri]**) (Fig. 1055) is an important complex of nerve-fibres and cells, which lies in a slight depression on the apex of the petrous portion of the temporal bone. In shape it is a flattened crescent with its convexity forward, measuring from 1.5–2 cm. in width and about 1 cm. in length. The surface of the ganglion presents an irregular longitudinal or reticular striation. From the anterior expanded convex border of the ganglion arise the ophthalmic and maxillary nerves and the sensory portion of the mandibular nerve, while its narrow concave posterior margin is continued into the sensory root of the fifth nerve. The ganglion lies in *Meckel's space* (**cavum Meckelii**), a cleft produced by a delamination of the dura mater, and comes in relation internally with the cavernous sinus and the internal carotid artery. Beneath, but unconnected with it, are the motor root of the trifacial and the great superficial petrosal nerve. In structure it resembles a spinal ganglion, being composed of the characteristically modified neurones, from whose single processes proceed the peripherally directed dendrites and the centrally coursing axones.

FIG. 1055.



Gasserian ganglion of left side viewed from above; sensory and motor roots and three divisions of trigeminal nerve are seen.

In addition to the three large trunks given off from the anterior margin, the **branches** of the Gasserian ganglion include some fine **meningeal filaments** which arise from the posterior end of the ganglion and are distributed to the adjacent dura mater.

Communications.—At its inner side the Gasserian ganglion receives filaments from the adjacent carotid plexus of the sympathetic, which end in relation with the cells of the ganglion.

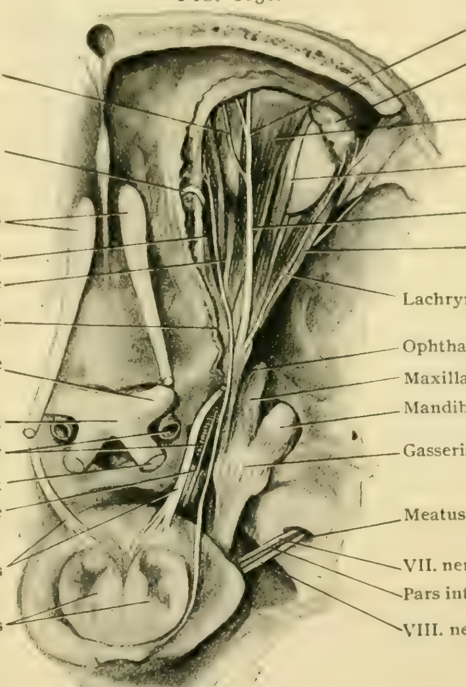
Divisions of the Trigeminal Nerve.—These are three in number, the *ophthalmic*, the *maxillary* and the *mandibular* nerves. They arise from the anterior

margin of the Gasserian ganglion, the formation of the mandibular nerve being completed by the accession of the motor root of the trigeminal.

I. **The Ophthalmic Nerve.**—The ophthalmic nerve (n. ophthalmicus) (Fig. 1056), the smallest of the three divisions, is purely sensory and supplies the upper eyelid, the conjunctiva, the eyeball, the lachrymal gland, caruncle and sac, the forehead and anterior part of the scalp, the frontal sinus and the root and anterior portion of the nose. It arises from the anterior margin of the Gasserian ganglion and passes upward and forward for about 25 mm. in the external wall of the cavernous sinus, lying below the fourth nerve. Reaching the sphenoidal fissure it breaks up into its terminal branches, which pass through the fissure into the orbit.

Branches and Distribution.—The branches of the ophthalmic nerve are: (1) the *recurrent*, (2) the *communicating*, (3) the *lachrymal*, (4) the *frontal*, and (5) the *nasal*, of which the last three are terminal branches.

FIG. 1056.



Roof of right orbit has been removed to expose branches of ophthalmic division of trigeminal nerve; Gasserian ganglion, and third, fourth, sixth, seventh and eighth nerves also seen.

1. The **recurrent branch** (n. tentorii) arises shortly after the nerve leaves the ganglion. It passes across and is adherent to the trochlear nerve and is distributed between the layers of the tentorium cerebelli.

2. The **communicating branches** are three slender filaments which are given off before the nerve breaks up into its terminal branches; they join the trunks of the third, fourth and sixth nerves, to whose muscles they supply sensory fibres. During its passage through the cavernous sinus, the ophthalmic nerve receives some tiny filaments from the cavernous sympathetic plexus.

3. The **lachrymal nerve** (n. lacrimalis) (Fig. 1053) is the smallest of the terminal branches. It lies to the outer side of the frontal nerve and traverses the outer angle of the sphenoidal fissure in its own sheath of dura mater. It passes above the origin of the orbital muscles and courses along the lateral wall of the orbit, above the external rectus, to the upper outer angle of the orbit, where it pierces the palpebral fascia near the external canthus to terminate in the upper eyelid. It supplies the lachrymal gland, the upper eyelid and the skin around the external canthus.

Within the orbit the lachrymal nerve **communicates** with the temporal branch of the temporo-malar nerve and on the face with the temporal branch of the facial. The latter is one of the numerous sensory-motor communications between the terminal fibres of the fifth and seventh nerves.

Variations.—Occasionally the lachrymal nerve seems to be partly derived from the trochlear; the true source of such fibres, however, is probably the ophthalmic nerve, by way of its communicating branch to the fourth. Considerable variation is found in connection with the temporal branch of the temporo-malar nerve. The lachrymal nerve or the temporal branch of the temporo-malar may be absent, the place of either being taken by the other, or the lachrymal may be small at its origin and later increased to normal size by accessions from the temporal branch of the temporo-malar.

4. The **frontal nerve** (**n. frontalis**) (Fig. 1053) is the largest branch of the ophthalmic. It enters the orbit, invested by its own dural sheath, through the sphenoidal fissure and above the orbital muscles and passes directly forward between the periosteum and the levator palpebræ superioris. At a variable point, usually about the middle of the orbit, it divides into its terminal branches, the (*a*) *supratrochlear* and (*b*) the *supraorbital*.

a. The **supratrochlear nerve** (**n. supratrochlearis**) is the smaller of the two terminal branches. It passes inward and forward over the pulley of the superior oblique and thence between the orbicularis palpebrarum and the frontal bone, leaving the orbit at its upper inner angle. Near the pulley it gives off a branch which joins the infratrochlear (Fig. 1057) and at the edge of the orbit supplies filaments (**nn. palpebrales superiores**) to the skin and conjunctiva of the upper eyelid. It then turns upward and subdivides into a number of small branches which pierce the substance of the frontalis and orbicularis palpebrarum muscles to supply the inner and lower part of the forehead.

b. The **supraorbital nerve** (**n. supraorbitalis**) (Fig. 1056) continues directly the course of the frontal nerve. It lies close to the periosteum throughout its entire orbital course and leaves the orbit through the supraorbital notch or foramen. In this situation it sends a small filament to the frontal sinus to supply its diploë and mucous membrane. As it leaves the orbit it supplies some fine twigs to the upper eyelid and then divides into a larger outer and smaller inner branch. These pass upward on the forehead beneath the frontalis muscle, occasionally occupying quite deep grooves in the frontal bone, and terminate by being distributed to the scalp and pericranium. The outer branch extends back nearly to the occipital bone, while the inner passes only a short distance posterior to the coronal suture.

Both branches of the frontal, the supratrochlear and the supraorbital, **communicate** with branches of the facial nerve and thereby supply sensory filaments to muscles supplied by the seventh.

Variations.—The nerve may divide before leaving the orbit and in that event only the outer branch passes through the normal osseous channel. The inner sometimes has a special groove, named by Henle the *frontal notch*.

5. The **nasal nerve** (**n. nasociliaris**) (Fig. 1057) is intermediate in size between the lachrymal and the frontal. It enters the orbit, clothed in dura mater, through the sphenoidal fissure, between the heads of the external rectus and between the superior and inferior divisions of the oculomotor nerve. Turning obliquely inward, it crosses the optic nerve and passes beneath the superior oblique and superior rectus muscles and above the internal rectus. Thence it traverses the anterior ethmoidal foramen to enter the cranial cavity, where it passes forward in a groove in the lateral part of the cribriform plate of the ethmoid bone. Leaving the cranium through the nasal fissure, the nerve enters the nasal fossa, where it breaks up into its three terminal branches.

Branches.—These are: (*a*) the *ganglionic*, (*b*) the *long ciliary*, (*c*) the *infratrochlear*, (*d*) the *internal nasal*, (*e*) the *external nasal* and (*f*) the *anterior nasal*, of which the last three are terminal branches.

a. The *ganglionic branch* (**radix longa**) (Fig. 1057) usually leaves the nerve between the heads of the external rectus and passes forward along the outer side of the optic nerve to enter the upper posterior portion of the ciliary ganglion, of which it forms the sensory or long root.

b. The *long ciliary branches* (**nn. ciliares longi**) (Fig. 1058) are two in number. They pass forward along the inner side of the optic nerve and, after joining one or more of the short ciliary nerves, pierce the sclerotic coat of the eye to be distributed to the iris, ciliary muscle and cornea.

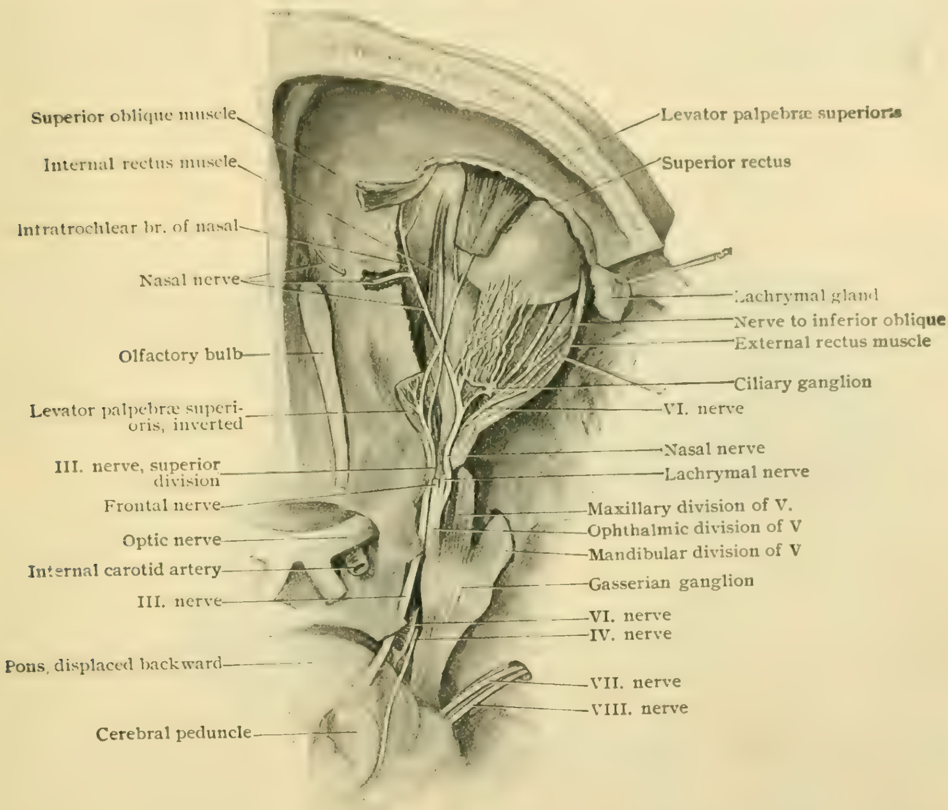
c. The *infratrochlear nerve* (n. infratrochlearis) (Fig. 1058) runs forward along the inner orbital wall and beneath the superior oblique muscle and its pulley to the inner end of the palpebral fissure, where it terminates. Near the pulley it receives a filament (the supratrochlear) from the frontal nerve. It supplies the skin of the upper eyelid and root of the nose, as well as the conjunctiva and the lachrymal caruncle and sac.

d. The *internal nasal* or *septal branch* (rr. mediales) (Fig. 1048) supplies the mucous membrane of the anterior portion of the septum.

e. The *external nasal branch* (rr. laterales) (Fig. 1047) supplies the front part of the middle and inferior turbinate bones and outer wall of the nasal fossa.

f. The *anterior nasal branch* (r. nasalis extremus) passes downward in a groove in the under side of the nasal bone and then between the lower end of the nasal bone and the

FIG. 1057.



Deeper dissection of right orbit, viewed from above; branches of nasal nerve shown.

upper lateral cartilage of the nose, finally emerging from under cover of the compressor naris muscle. It supplies the skin of the fore-part and tip of the nose.

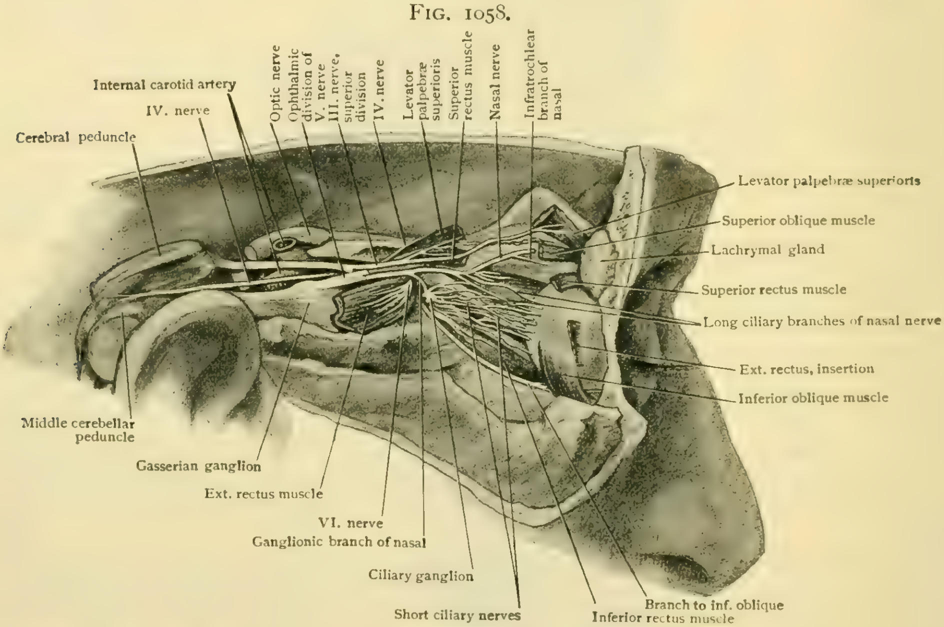
Variations.—The nasal nerve may send branches to the superior and internal recti and levator palpebræ superioris muscles. In one case a small ganglion connected with the nasal nerve sent fibres to the third and sixth nerves. Instances are recorded of absence of the infratrochlear branch, the deficiency being supplied by the supratrochlear. Branches to the frontal and ethmoidal sinuses are described as being given off in the anterior ethmoidal foramen, and a branch has been found which passes through the posterior ethmoidal foramen to supply the sphenoidal and posterior ethmoidal sinuses. The latter has been called by Luschka the *spheno-ethmoidal* and by Krause the *posterior ethmoidal* branch.

The Ganglia associated with the Trigeminal Nerve.—Four small ganglia are connected with the extracranial portion of the fifth nerve. They are the ciliary, the spheno-palatine, the otic and the submaxillary. The ciliary ganglion is associated

with the ophthalmic nerve, the spheno-palatine with the maxillary and the otic and submaxillary with the mandibular. Each is the recipient of three *roots*—a *motor*, a *sensory* and a *sympathetic*—and from each ganglion branches are given off to more or less contiguous structures.

The significance of these bodies—whether of the nature of spinal or sympathetic ganglia—has long been a subject of discussion. The close resemblance of their nerve-cells to the stellate neurones of undoubted sympathetic ganglia, as shown by the investigations of Retzius, Kölliker and others, as well as the results of experimental studies (Apolant), justifies the conclusion that these ganglia are properly regarded as belonging to the sympathetic group. They are, therefore, probably stations in which certain motor and secretory fibres contributed by various nerves end in arborizations around sympathetic neurones, from which axones pass for the immediate supply of involuntary muscle and glandular tissue. The fact that these small ganglia are derivations of the early Gasserian ganglion is in accord with the mode of origin of the sympathetic ganglia elsewhere (page 1013).

FIG. 1058.



Dissection of right orbit after removal of its lateral wall; external and superior eye-muscles have been cut and displaced to expose ciliary ganglion and nerves.

The Ciliary Ganglion.—The *ciliary*, *ophthalmic* or *lenticular* ganglion (**g. ciliare**) (Fig. 1058), as it is varyingly called, is a small reddish mass, about 2 mm. long in the antero-posterior direction, and approximately quadrilateral in outline. It is compressed laterally and to each angle is attached one or more bundles of nerve-fibres. It lies near the apex of the orbit on the outer side of the optic nerve, between the latter and the external rectus muscle and anterior to the ophthalmic artery.

The nerve-cells within the ganglion are chiefly multipolar elements, which closely resemble sympathetic neurones (Retzius) and send their axones towards the eye by way of the short ciliary nerves.

Roots.—All of these enter the posterior margin of the ganglion. The *motor* or *short root* (**radix brevis**), the thickest of the roots and sometimes double, is an offshoot from the branch of the oculomotor nerve which supplies the inferior oblique muscle. It is short and comparatively robust and joins the postero-inferior portion of the ganglion. The *sensory* or *long root* (**radix longa**) arises from the nasal branch of the ophthalmic, leaving the latter between the heads of the external rectus. It is long and slender and passes forward to enter the upper posterior angle of the ganglion, occasionally being fused with the sympathetic root. The *sympathetic root* (**radix

media) is a tiny filament which arises from the cavernous plexus and runs forward to enter, either alone or with the sensory root, the upper posterior angle of the ganglion.

Branches.—These are the short ciliary nerves (nn. ciliares breves). They number from four to six and by division are increased to twelve or twenty before reaching the eyeball (Fig. 1058). They arise as two fasciculi from the upper and lower anterior angles of the ganglion and pass forward above and below the optic nerve. The lower set is the more numerous and on its way forward is joined by the long ciliary nerves from the nasal, with which one or more of its constituent branches usually fuse. After piercing the sclerotic coat in two groups, one below and the other above the entrance of the optic nerve, they pass forward in grooves on the inner surface of the sclerotic to supply the choroid, iris, ciliary muscle and cornea.

The short ciliary nerves include three sets of fibres: (1) Sympathetic fibres destined for the walls of the blood-vessels and the radial (dilator) muscle of the iris; these are links in the chain made up of (*a*) white rami communicantes from the upper thoracic spinal nerves to the cervical gangliated cord, and (*b*) the axones of neurones within the sympathetic ganglia. (2) Fibres supplying the ciliary muscle and the circular (sphincter) muscle of the iris, which, while in a sense the continuations of the oculomotor nerves, are immediately the axones of the stellate sympathetic neurones within the ciliary ganglion. (3) Trigeminal fibres which transmit sensory impulses from the interior of the eyeball, in conjunction with the long ciliary nerves.

Variations.—The motor root occasionally bifurcates before it reaches the ganglion. As noted above, the sensory and sympathetic roots frequently form a common trunk of entrance into the ganglion. Occasionally the ganglion is very small, due possibly to the scattering of its constituent neurones among the nerves connected with it (Quain). Additional roots have been described as coming from the superior division of the oculomotor, from the trochlear, from the lachrymal, from the abducent and from the spheno-palatine ganglion. Absence of the sensory root has been noted, the deficiency possibly being corrected by the long ciliary nerves conveying sensory fibres directly from the nasal to their destination, instead of these fibres passing through the ganglion. The sympathetic root may be multiple, a condition held by some to be normal, some of the fibres accompanying the oculomotor nerve.

II. The Maxillary Nerve or *superior maxillary nerve* (n. maxillaris) is purely sensory and is intermediate in size between the ophthalmic and mandibular divisions of the trigeminus. It supplies the cheek, the anterior portion of the temporal region, the lower eyelid, the side of the nose, the upper lip, the upper teeth, and the mucous membrane of the nose, naso-pharynx, maxillary antrum, posterior ethmoidal cells, soft palate, tonsil and roof of the mouth. Arising from the middle of the anterior convex border of the Gasserian ganglion, it passes forward beneath the dura mater in the middle cranial fossa, lying below the cavernous sinus (Fig. 1053). The nerve leaves the cranium through the foramen rotundum, traverses the spheno-maxillary fossa and enters the orbital cavity by means of the spheno-maxillary fissure. It occupies and then parallels the floor of the orbit in the infraorbital groove and canal, finally emerging on the face by passing through the infraorbital foramen. Here it breaks up fanlike into three terminal groups of branches (Fig. 1060).

Branches and Distribution.—Branches are given off from the maxillary nerve in the cranium, in the spheno-maxillary fossa, in the infraorbital canal and on the face. These are: within the **cranium**, (1) the *recurrent;* within the **spheno-maxillary fossa**, (2) the *spheno-palatine*, (3) the *posterior superior dental* and (4) the *temporo-malar;* in the **infraorbital canal**, (5) the *middle superior dental* and (6) the *anterior superior dental;* on the **face** (7) the *inferior palpebral*, (8) the *lateral nasal* and (9) the *superior labial*. The last three are terminal branches.

1. The **recurrent branch** (n. meningeus) is given off before the maxillary nerve passes through the foramen rotundum. It supplies the dura mater in the middle cranial fossa.

2. The two or three **spheno-palatine branches** (nn. sphenopalatini) (Fig. 1061) arise in the spheno-maxillary fossa. They are short and thick and pass directly downward to the upper margin of the spheno-palatine ganglion, whose sensory root they supply. Only a small part of their fibres actually traverse the ganglion, the much larger part passing lateral to or in front of the ganglion, to be continued

into the orbital, posterior nasal and palatine branches. While in neither case are the trigeminal fibres interrupted in the ganglion, in both instances they receive sympathetic fibres from the ganglion, which accompany the trigeminal ones.

3. The **posterior superior dental nerve** (**r. alveolaris superior posterior**) (Fig. 1060) is frequently double. It passes downward and forward with the posterior dental artery through the pterygo-maxillary fissure to reach the zygomatic surface of the maxilla. It supplies tiny filaments to the gum and adjacent mucous membrane of the cheek and enters the posterior dental canals to supply the molar teeth. It forms a fine plexus (**plexus dentalis superior**) (Fig. 1059) with the middle and anterior superior dental nerves.

Variation.—In the absence of the buccal branch of the fifth, the posterior superior dental has been observed to be of large size and to assume the distribution of the buccal.

4. The **temporo-malar** or **orbital nerve** (**n. zygomaticus**) (Fig. 1053) after arising from the maxillary passes from the spheno-maxillary fossa into the orbit

FIG. 1059.

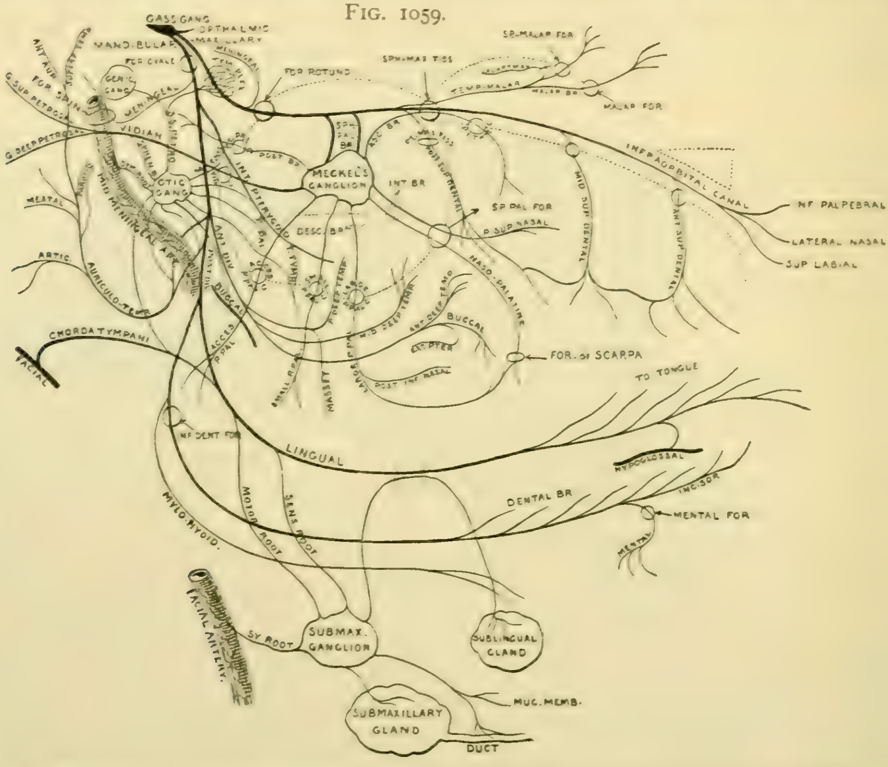


Diagram showing plan and connections of second and third divisions of trigeminus and their ganglia.

through the spheno-maxillary fissure. It courses along the external orbital wall and divides into a temporal and a malar branch. The *temporal branch* (**n. zygomaticotemporalis**) after inosculating with the lachrymal nerve passes through the spheno-malar foramen to enter the temporal fossa. It then runs between the bone and the temporal muscle and pierces the temporal fascia to be distributed to the skin of the anterior temporal region. It communicates with the temporal branch of the facial nerve. The *malar branch* (**n. zygomaticofacialis**) traverses the malar foramen to supply the skin of the malar region. It joins with filaments from the malar branch of the seventh.

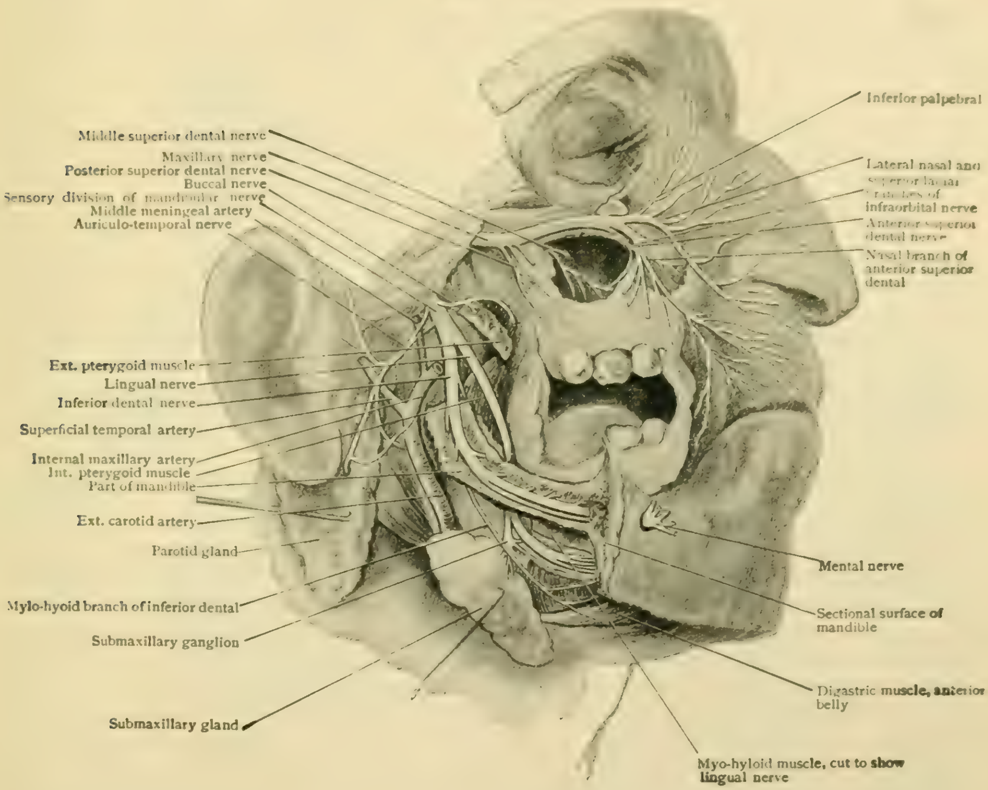
Variations.—The nerve may pass through the malar bone before it divides, both branches may pass separately through canals confined to the malar bone, or the temporal branch may pass

through the spheno-maxillary fissure. Either branch may be absent or smaller than normal, the other branch supplying the deficiency. The malar may be replaced in its distribution by the infraorbital and the temporal may be substituted or augmented by the lachrymal.

5. The **middle superior dental nerve** (r. alveolaris superior medius) leaves the maxillary in the posterior part of the infraorbital canal. It occasionally arises from the anterior superior dental. It passes down in a canal in the outer wall of the maxillary antrum and after forming a plexus with the other two dental nerves supplies the premolar teeth.

6. The **anterior superior dental nerve** (r. alveolaris superior anterior) is the largest of the three superior dental nerves. It arises from the maxillary just before the exit of the latter at the infraorbital foramen and descends in a canal in the anterior wall of the antrum. It gives off a *nasal branch*, which enters the nose

FIG. 1060.



Dissection showing maxillary and mandibular nerves and their branches; outer wall of orbit, part of facial wall of maxillary sinus and part of mandible have been removed.

through a tiny canal in the outer wall of the inferior meatus of the nose and supplies the mucous membrane of the anterior part of the inferior nasal meatus and floor of the nose. After helping to form the superior dental plexus, the anterior superior dental supplies the canine and incisor teeth.

Two thickenings are sometimes found in the superior dental plexus. One of these, known as the *ganglion of Valentin*, lies above the tip of the root of the second premolar tooth, at the junction of the middle and posterior superior dental nerves; and the other, sometimes called the *ganglion of Bochdalek*, is situated more anteriorly, at the junction of the middle and anterior dental nerves. Neither of these enlargements is a true ganglion, being without nerve-cells and consisting of interlacing bundles of nerve-fibres.

7. The **inferior palpebral branches** (**rr. palpebrales inferiores**) (Fig. 1060) usually two in number, are the smallest of the terminal branches. They pass upward from the infraorbital foramen, pierce the origin of the levator labii superioris, pass around the lower margin of the orbicularis palpebrarum and supply the conjunctiva and skin of the lower eyelid.

8. The **lateral nasal branches** (**rr. nasales externi**) (Fig. 1060), from two to four in number, pass inward under the levator labii superioris alæque nasi and supply the skin of the side of the nose.

9. The **superior labial branches** (**rr. labiales superiores**) (Fig. 1060), two to four in number, are the largest of the terminal branches. They pass downward under the levator labii superioris and, after supplying the anterior portion of the skin of the cheek, terminate in the mucous membrane and skin of the upper lip.

The last three branches inosculate freely under the levator labii superioris with the infraorbital branch of the facial, forming the *infraorbital plexus* (Fig. 1068).

The Spheno-Palatine Ganglion.—The spheno-palatine ganglion (**g. sphenopalatinum**), also known as *Meckel's*, the *spheno-maxillary* or the *nasal ganglion*, is a small triangular reddish-gray body, with the apex directed posteriorly, situated in the upper portion of the spheno-maxillary fossa. It is flat on its mesial surface, and convex on its lateral, and measures about 5 mm. in length. It lies in close proximity to the spheno-palatine foramen and just beneath the maxillary branch of the trigeminal nerve (Fig. 1061). The ganglion is regarded as belonging to the series of sympathetic nodes, and consists of an interlacement of nerve-fibres in which are embedded numerous stellate sympathetic neurones.

Roots.—The *sensory root* consists of two, sometimes three, short stout filaments, the **spheno-palatine nerves** (**nn. sphenopalatini**), which pass directly downward from the lower margin of the maxillary nerve to the upper border of the ganglion. While some few of the fibres of this root are axones of the sympathetic ganglion-cells, the great majority are dendrites of the cells of the Gasserian ganglion which pass to a limited extent through, but mostly around, the spheno-palatine ganglion independently of its cellular elements. They are continued entirely into the various trunks that are usually described as branches of distribution of the ganglion (see below).

The *motor root* is the **great superficial petrosal nerve** (**n. petrosus superficialis major**) which, in all probability, carries sensory as well as motor fibres. It arises from the facial nerve in the facial canal, passes through the hiatus Fallopii and a groove in the petrous portion of the temporal bone and then under the Gasserian ganglion to reach the cartilage occupying the middle lacerated foramen. Here the great superficial petrosal nerve is joined by the *sympathetic root*, the **great deep petrosal**, (**n. petrosus profundus**), which is a branch from the carotid plexus. The two great petrosal nerves fuse over the cartilage at the middle lacerated foramen to form the Vidian nerve (**n. canalis pterygoidei [Vidii]**) (Fig. 1061), which traverses the canal of the same name and enters the spheno-maxillary fossa to join the spheno-palatine ganglion. In its course through the canal the Vidian nerve gives off a few tiny *nasal branches*, which, composed of trigeminal and sympathetic fibres, supply the pharyngeal ostium of the Eustachian tube and the posterior part of the roof of the nose and the nasal septum. While in the canal, the Vidian nerve receives a filament from the otic ganglion.

In addition to supplying (according to many anatomists) motor fibres to the levator palati and azygos uvulæ muscles, some of the facial fibres are especially destined for glandular structures. Such fibres are probably interrupted around the stellate cells of the spheno-palatine ganglion, the axones of which then complete the paths for the secretory impulses. The sensory constituents of the great superficial petrosal nerve are, perhaps, of two kinds: (*a*) fibres from the cells of the geniculate ganglion of the facial to the palatine taste-buds, and (*b*) recurrent trigeminal fibres, that, by way of the maxillary, spheno-palatine and great superficial petrosal nerves, are distributed with the peripheral branches of the Vidian or of the facial nerve.

The great deep petrosal nerve represents the association cord between the superior cervical sympathetic and the spheno-palatine ganglion. Many of its fibres end in arborizations around the stellate spheno-palatine cells, from which, in turn, axones pass to blood-vessels and glands by way of the ganglionic branches of distribution.

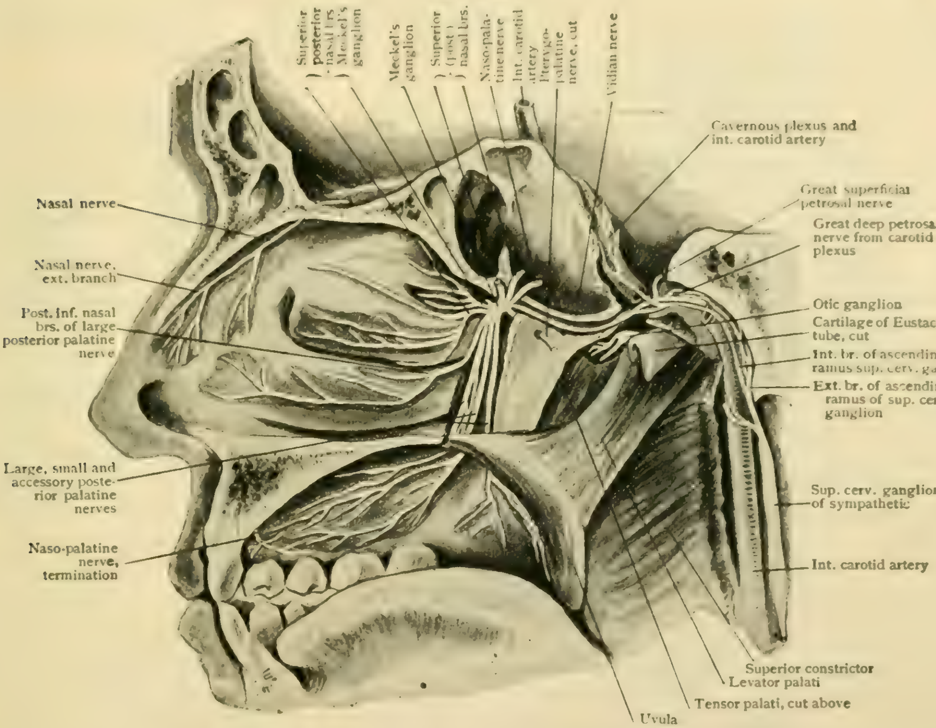
Branches.—The branches of distribution of the spheno-palatine ganglion are conveniently grouped into four sets: (1) the *ascending*, (2) the *descending*, (3) the *internal* and (4) the *posterior*.

1. The **ascending** or **orbital branches** (rr. orbitales) (Fig. 1059) are two or three tiny filaments, which pass into the orbit through the spheno-maxillary fissure and, after traversing the posterior ethmoidal canal or a small special aperture, are distributed to the sphenoidal and posterior ethmoidal air-cells and the periosteum of the orbit.

2. The **descending branches** (**nn. palatini**) (Fig. 1059) are three: (*a*) the *large posterior palatine*, (*b*) the *small posterior palatine*, and (*c*) the *accessory posterior palatine nerves.*

a. The *large posterior palatine nerve* (**n. palatinus anterior**) leaves the spheno-maxillary fossa by means of the large posterior palatine canal, through which it descends to the inferior surface of the hard palate. While in the canal it gives off one or two *posterior inferior nasal* branches

FIG. 1061.



Dissection showing spheno-palatine and otic ganglia viewed from within.

(**rr. nasales posteriores inferiores**), which, escaping through small apertures in the perpendicular plate of the palate bone, enter the nasal fossa and supply the mucous membrane of all but the anterior portion of the inferior turbinate bone and the adjoining portions of the middle and inferior nasal meatuses. Emerging from its canal the main nerve passes forward in a groove on the inferior aspect of the hard palate and inosculates with the terminal filaments of the naso-palatine nerve. It supplies the hard palate and its mucous membrane, as well as the inner side of the gum.

b. The *small posterior palatine nerve* (**n. palatinus posterior**) descends in the small posterior palatine canal. It supplies sensory filaments to the mucous membrane of the soft palate and the tonsil and motor ones to the levator palati and azygos uvulæ muscles.

c. The *accessory posterior palatine nerves* (**nn. palatinus medius**) are one or more small filaments which pass through the accessory posterior palatine canals and supply the mucous membrane of the soft palate and tonsil.

3. The **internal branches** (rr. nasales posteriores superiores) (Fig. 1059) pass from the spheno-maxillary into the nasal fossa through the spheno-palatine foramen. They are: (*a*) the *posterior superior nasal* and (*b*) the *naso-palatine nerve.*

a. The *posterior superior nasal nerve* (rr. laterales) supplies the mucous membrane of the posterior superior portion of the outer wall of the nasal fossa.

b. The *naso-palatine nerve* (n. nasopalatinus) (Fig. 1059) crosses the roof of the nasal chamber and passes downward and forward in a groove in the vomer and septal cartilage to reach the anterior palatine canal. It then passes through the foramen of Scarpa, the left nerve through the anterior and the right one through the posterior canal, the two nerves forming in this situation a fine plexus. Having reached the inferior surface of the hard palate, the naso-palatine inosculates with the large posterior palatine nerve. It supplies the roof and septum of the nose and that portion of the hard palate which lies posterior to the incisor teeth.

4. The **posterior branch** (Fig. 1059) also known as the *pharyngeal* or *pterygo-palatine*, leaves the spheno-maxillary fossa through the pterygo-palatine canal and supplies the mucous membrane of the naso-pharynx in the region of the fossa of Rosenmüller.

Variations.—Branches of the ganglion have been described as passing to the abducent nerve, to the ciliary ganglion and to the optic nerve or its sheath. The accessory posterior palatine nerve is sometimes absent. Quite frequently the left naso-palatine nerve passes through the posterior foramen of Scarpa and the right nerve through the anterior.

III. The Mandibular Nerve.—The mandibular or *inferior maxillary* branch (n. mandibularis) of the trigeminal nerve is the largest of its three divisions and, being a mixed nerve, consists of two portions, one sensory and the other motor. The *sensory part* is the larger and arises from the lower anterior portion of the Gasserian ganglion. The smaller *motor part* is the motor root of the trigeminal nerve, which contributes exclusively to this division of the fifth nerve. Although these two portions are intimately associated in their passage through the foramen ovale, the motor bundle lying to the median side of the sensory, it is not until they emerge from the skull that they unite, immediately below the lower margin of the foramen ovale, to form the mandibular nerve. The sensory portion supplies the skin of the side of the head, the auricle of the ear, the external auditory meatus, the lower portion of the face and the lower lip, the mucous membrane of the mouth, tongue and mastoid cells, and the lower teeth and gums, the salivary glands, the temporo-mandibular articulation, the dura mater and the skull. The motor portion supplies the muscles of mastication (the temporal, the masseter and the external and internal pterygoids), the anterior belly of the digastric, the mylo-hyoid, the tensor palati and the tensor tympani muscles. By union of the two constituents, a thick common trunk is formed, which, after a course of from 2–3 mm., separates under cover of the external pterygoid muscle into an *anterior* and a *posterior division* (Fig. 1063).

Branches and Distribution.—The branches from the main trunk of the mandibular nerve are: (1) the *recurrent branch* and (2) the *internal pterygoid nerve*.

1. The **recurrent branch** (n. spinosus) arises just beneath the foramen ovale and accompanies the middle meningeal artery into the cranium through the foramen spinosum. It then divides into two branches, the anterior of which supplies the greater wing of the sphenoid and the adjacent dura mater, while the posterior passes through the petro-squamous suture and supplies the mucous membrane of the mastoid air-cells.

2. The **internal pterygoid nerve** (n. pterygoideus internus) (Fig. 1059) passes downward on the mesial side of its muscle and, in addition to supplying the pterygoid muscle, gives off the motor root of the otic ganglion and filaments to the tensor tympani and tensor palati muscles.

The Anterior Division of the mandibular nerve (n. masticatorius) is motor, with the exception of its buccal branch, and receives almost the entire motor constituent of the trigeminal. It passes downward and forward for a short distance under the external pterygoid muscle and then breaks up into its branches.

Branches.—These are: (1) the *masseteric*, (2) the *external pterygoid*, (3) the *deep temporal* and (4) the *buccal nerve*.

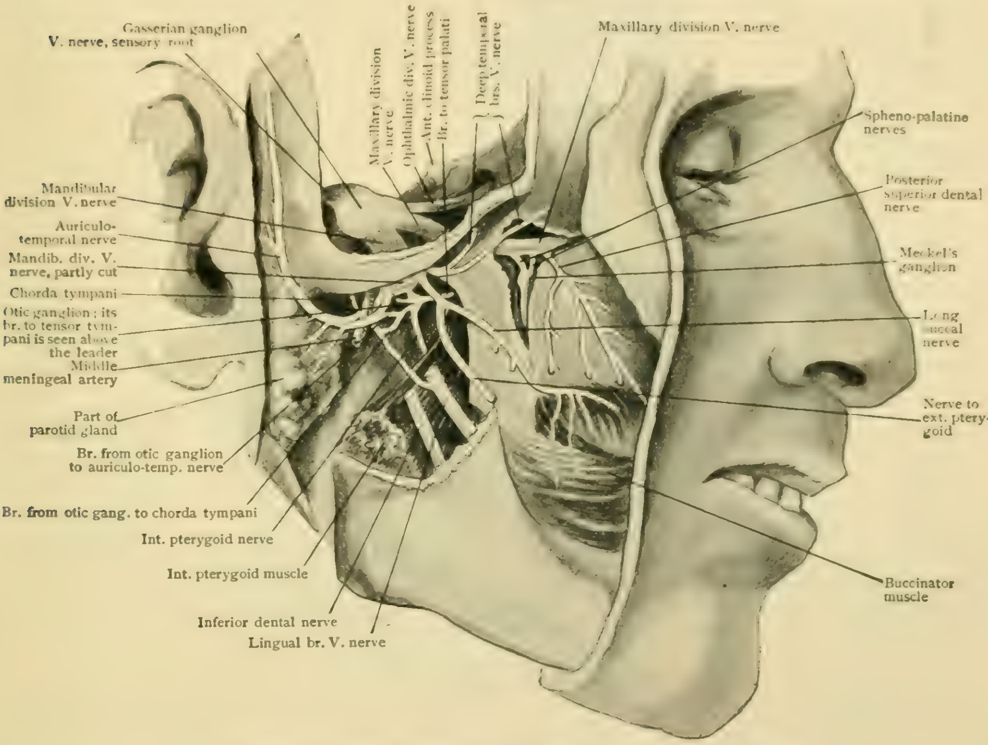
1. The **masseteric nerve** (n. massetericus) (Fig. 1063) passes over the upper border of the external pterygoid and behind the posterior margin of the temporal muscle. It takes a course horizontally outward and traverses the sigmoid

notch of the mandible to enter the posterior portion of the mesial surface of the masseter. It supplies one or two filaments to the temporo-mandibular articulation.

2. The **external pterygoid nerve** (**n. pterygoideus externus**) (Fig. 1063), usually takes its origin as a common trunk with the buccal nerve. It enters the deep surface of the external pterygoid.

3. The **deep temporal nerves** (**nn. temporales profundi anterior et posterior**) (Fig. 1063), are usually three or two in number. The *anterior* accompanies the buccal nerve between the heads of the external pterygoid, after which it passes upward to supply the anterior portion of the temporal muscle. The *middle* passes outward across the upper margin of the external pterygoid and then upward close to the bone to enter the deep surface of the temporal muscle. It often fuses with either the anterior or posterior deep temporal, thus reducing the number of temporal

FIG. 1062.



Dissection showing lateral view of spheno-palatine and otic ganglia.

nerves to two. The *posterior* frequently accompanies the nerve to the masseter for a variable distance, after which it turns upward along the bone to enter the deep surface of the posterior portion of the muscle.

4. The **buccal nerve** (**n. buccinatorius**) (Fig. 1062) is purely sensory. It arises in common with the external pterygoid and anterior deep temporal nerves and is accompanied by the latter between the heads of the external pterygoid. Passing downward on the inner side of the temporal muscle it reaches the outer surface of the buccinator, where it breaks up into several branches which form a plexus around the facial vein, with the buccal branch of the facial nerve. Some of its branches pierce the buccinator muscle to supply the mucous membrane of the cheek as far forward as the angle of the mouth, while the others supply the skin of the cheek.

Variations.—Instead of lying to the inner side, the nerve may pierce the temporal muscle. It may be derived from the posterior superior dental nerve or from the inferior dental, in the latter instance emerging from the inferior dental canal by a small foramen in the alveolar border

of the mandible just anterior to the ramus. It has been seen in one case to arise directly from the Gasserian ganglion and emerge from the cranium through a special foramen situated between the foramina rotundum and ovale.

The Posterior Division of the mandibular nerve is sensory, with the exception of the mylo-hyoid nerve. It passes downward beneath the external pterygoid and, after giving off the two roots of the *auriculo-temporal nerve*, terminates by dividing into the *lingual* and the *inferior dental nerve*.

Branches.—These are : (1) the *auriculo-temporal*, (2) the *lingual* and (3) the *inferior dental*.

1. The **auriculo-temporal nerve** (**n. auriculotemporalis**) (Fig. 1063) arises just below the foramen ovale by two roots which enclose between them the middle meningeal artery. It passes backward beneath the external pterygoid muscle and between the spheno-mandibular ligament and the neck of the mandible, and then turns upward through the parotid gland between the temporo-mandibular articulation and the external ear. Emerging from the upper margin of the gland, the nerve passes over the root of the zygoma and ascends to the temporal region behind and in company with the superficial temporal artery.

Branches.—These are : (*a*) the *articular*, (*b*) the *parotid*, (*c*) the *meatal*, (*d*) the *anterior auricular* and (*e*) the *superficial temporal*. The last three are terminal branches.

a. The **articular branches** (**rr. articulares**) are one or two delicate filaments which enter the posterior portion of the temporo-mandibular articulation.

b. The **parotid branches** (**rr. parotidei**) pass to the gland ; they arise either from the auriculo-temporal or from its communicating filaments with the facial nerve.

c. The **meatal branches** (**nn. meatus auditorii externi**) are two in number, an upper and a lower. They enter the external auditory canal between the bone and the cartilage and supply the skin covering the corresponding parts of the meatus, the upper branch in addition sending a twig (**r. membranae tympani**) to the tympanic membrane.

d. The **anterior auricular nerves** (**nn. auriculares anteriores**), usually two in number, supply skin of the tragus and of the upper anterior portion of the auricle.

e. The **superficial temporal nerve** (**rr. temporales superficiales**) (Fig. 1068) breaks up into a number of fine twigs which supply the skin of the temporal region and of the scalp almost to the sagittal suture.

The auriculo-temporal **communicates** by its roots, close to their origin, with branches from the otic ganglion, and by its parotid and superficial temporal branches with the facial nerve. By the first of these communications secretory fibres of the glosso-pharyngeal and sympathetic fibres are carried to the parotid gland ; by means of the second junction sensory trigeminal fibres accompany the peripheral motor filaments of the facial.

Variations.—In a specimen found in the anatomical laboratory of the University of Pennsylvania, the middle meningeal artery, instead of passing between the two roots of the nerve, pierced the anterior one.

2. The **lingual nerve** (**n. lingualis**) (Fig. 1079) is the smaller of the terminal branches of the mandibular nerve. Lying internal and anterior to the inferior dental nerve, it passes downward beneath the external pterygoid as far as the lower border of that muscle. It is usually connected with the inferior dental nerve by an oblique strand of fibres, which occasionally crosses the internal maxillary artery and, close to its origin, it is additionally joined at an acute angle by the chorda tympani nerve. After emerging from under cover of the external pterygoid, it passes between the internal pterygoid and the ramus of the mandible. It then turns inward, forward and downward under the mucous membrane of the floor of the mouth, crossing over the superior border of the superior constrictor of the pharynx and the deep portion of the submaxillary gland, and passes under the submaxillary duct between the mylo-hyoid and hyo-glossus muscles. Reaching the side of the tongue the nerve continues forward to the apex, lying just beneath the mucous membrane.

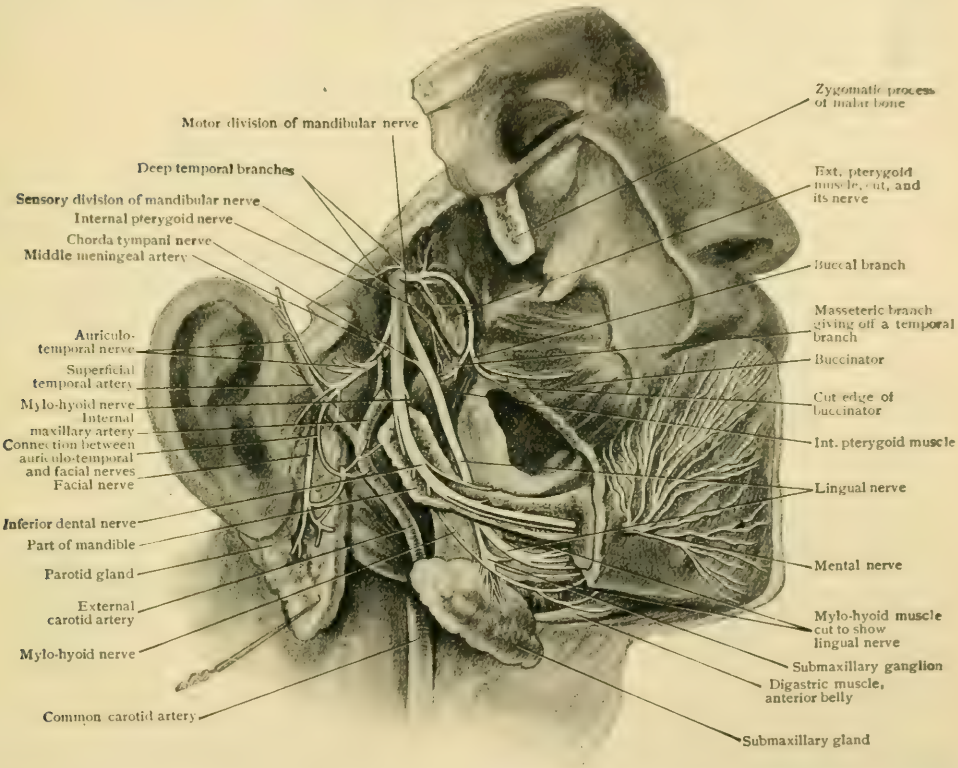
Branches.—The lingual nerve supplies small filaments to the sublingual gland, the floor and side of the mouth, the side of the tongue and the lower gum. It gives off the sensory root of the submaxillary ganglion and its terminal filaments (**rr. linguales**) pass upward through the muscles of the tongue to supply the mucous

membrane of the anterior two-thirds of the dorsum. Its fibres have their main termination in the filiform and fungiform papillæ.

The lingual nerve **communicates** with the chorda tympani and the inferior dental and in its anterior portion forms loops with the hypoglossal.

3. The **inferior dental nerve** (**n. alveolaris inferior**) (Fig. 1063) is the larger of the terminal branches of the mandibular. Lying posterior and external to the lingual, to which it is connected by a small nerve strand, it passes downward and forward under cover of the external pterygoid. Leaving the lower margin of that muscle, it runs between the ramus of the mandible and the spheno-mandibular ligament and enters the inferior dental canal, along which it courses in company

FIG. 1063.



Dissection showing mandibular nerve and its branches; mandible has been partially removed, exposing inferior dental nerve in its canal.

with the inferior dental artery, and supplies filaments to the teeth, as far as the mental foramen. Here the nerve breaks up into its terminal branches, one of which, the incisor, continues within the mandible to the mid-line, while the other and larger, the mental, emerges at the mental foramen.

Branches.—These are: (*a*) the *mylo-hyoid*, (*b*) the *dental*, (*c*) the *incisor* and (*d*) the *mental*, of which the last two are terminal branches.

a. The *mylo-hyoid nerve* (**n. mylohyoideus**) (Fig. 1063) is the only motor strand in the posterior division of the mandibular nerve. It arises from the inferior dental nerve, just before the latter enters its bony canal, and passes downward and forward in the mylo-hyoid groove, sometimes a canal for part of the way, in the mandible. The nerve descends into the digastric triangle and reaches the inferior surface of the mylo-hyoid muscle, in this situation being overlain by the submaxillary gland and the facial artery and vein. It here breaks up into filaments which supply the mylo-hyoid muscle and the anterior belly of the digastric.

b. The *dental branches* (**rr. dentales inferiores**) are given off as the nerve traverses the inferior dental canal. They combine and unite to form the *inferior dental plexus* (**plexus

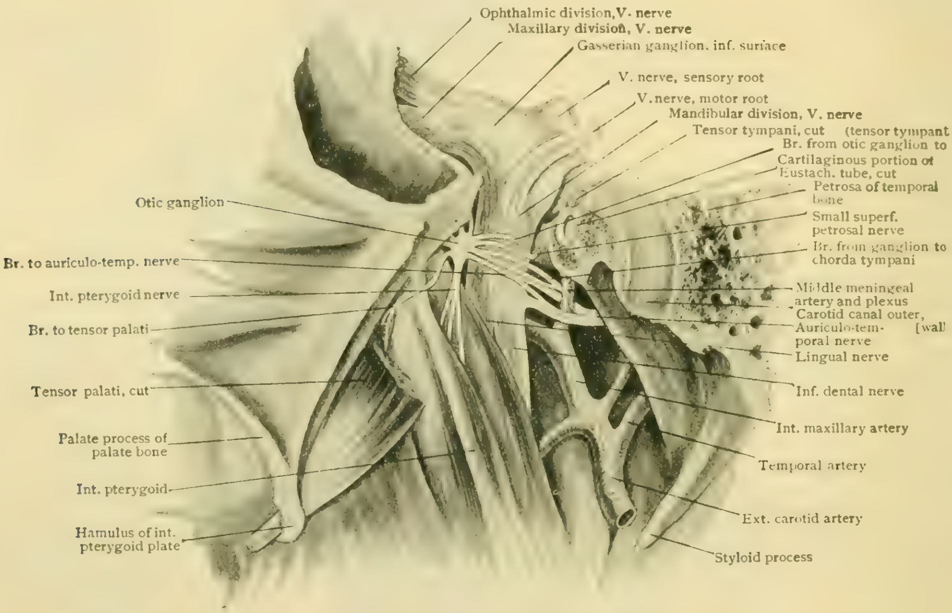
dentalis inferior) which supplies filaments to the molar and premolar teeth, one filament to each fang, and the adjacent portion of the gum.

c. The *incisor branch* (**n. alveolaris inferior anterior**) is the smaller of the terminal divisions and continues forward within the mandible the course of the inferior dental nerve from the mental foramen to the mid-line. It supplies the canine and incisor teeth.

d. The *mental nerve* (**n. mentalis**) (Fig. 1063) is much the larger terminal branch of the inferior dental. Emerging from the mental foramen, it breaks up under cover of the depressor anguli oris muscle into a number of filaments which supply the skin of the chin and the integument and mucous membrane of the lower lip. It forms a free communication with the supramandibular branch of the facial nerve.

The Otic Ganglion.—The otic or *Arnold's ganglion* (**g. oticum**) (Fig. 1064) is one of the two ganglia associated with the mandibular nerve. It is a small flattened

FIG. 1064.



Otic ganglion and branches seen from mesial aspect, section of skull being not sagittal, but approaching plane of long axis of petrosa.

body, of irregularly oval or stellate outline and reddish-gray color, and measures about 4 mm. in its longest or antero-posterior dimension. It lies just below the foramen ovale on the mesial side of the mandibular nerve and covers or even encloses the origin of the internal pterygoid nerve. Internally the ganglion is in relation with the tensor palati muscle and the cartilaginous portion of the Eustachian tube and posteriorly with the middle meningeal artery. It is a sympathetic ganglion and contains numerous stellate neurones which are characteristic of such structures.

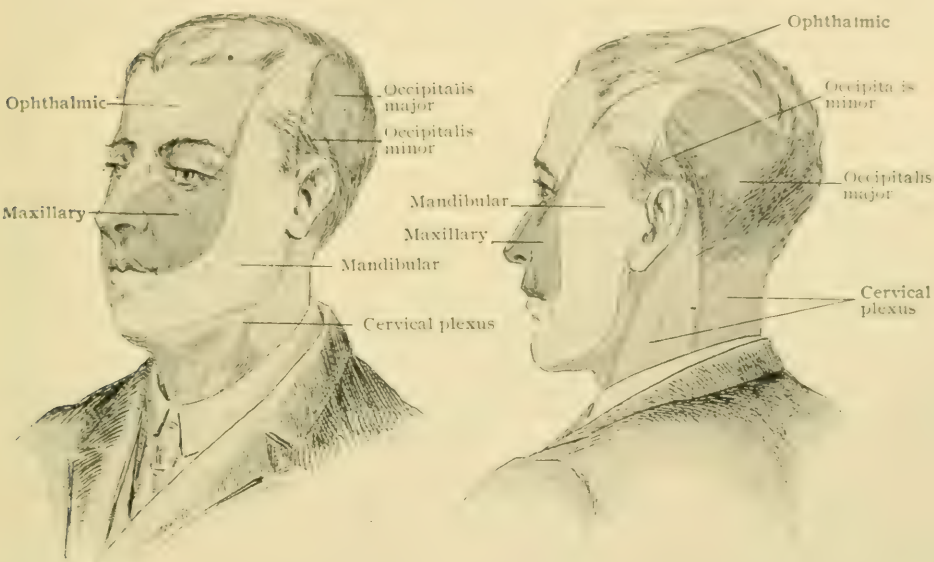
Roots.—Of the communications that the otic ganglion receives from several sources, some are regarded as its roots, of which the *sensory root* is contributed by **small superficial petrosal nerve** (**n. petrosus superficialis minor**). The latter establishes connection between the otic ganglion and the petrous ganglion of the glossopharyngeal nerve by way of its tympanic branch (page 1075) on the one hand and, by means of communicating filaments, between the otic and the geniculate ganglion of the facial nerve on the other. As the continuation of the tympanic nerve, after union with the filaments from the geniculate ganglion, the small superficial petrosal leaves the upper and fore part of the tympanic cavity, traverses a small canal in the temporal bone, and emerges on the upper surface of the latter, to the outer side of the hiatus Fallopii. It then turns downward, passes through the petro-sphenoidal fissure or through a special canal in the sphenoid bone, and joins the otic ganglion.

By means of these connections and the branches of distribution from the otic ganglion, secretory fibres are carried along with those of the auriculo-temporal (page 1244) to the parotid gland. The small superficial petrosal nerve also contains taste-fibres, which pass either to the petrous ganglion of the ninth or to the geniculate ganglion of the seventh, and thence centralward to the reception-nuclei in the medulla.

The *motor root* is a branch from the internal pterygoid nerve. The *sympathetic root* is represented by one or two nerve-filaments from the plexus on the middle meningeal artery. The ganglion also receives the *sphenoidal branch* from the Vidian nerve.

Branches.—A number of delicate strands pass from the otic ganglion to adjacent nerves. These so-called branches of distribution include: (*a*) two or more filaments which join the roots of the auriculo-temporal nerve and so convey secretory fibres from the glosso-pharyngeal to the parotid gland, (*b*) a communicating branch

FIG. 1065.



Diagrams showing distribution of cutaneous branches of trigeminal and cervical spinal nerves.

to the chorda tympani and (*c*) another to the buccal nerve, (*d*) a branch to the internal pterygoid nerve, and (*e*) and (*f*) branches to the nerves supplying the tensor palati and tensor tympani muscles.

The Submaxillary Ganglion.—The submaxillary ganglion (g. submaxillare) (Fig. 1063) is a reddish triangular or fusiform body, measuring from 2–3 mm. in its greatest length, and is the smallest of the sympathetic ganglia connected with the fifth nerve. It is situated above the deep portion of the submaxillary gland and upon the hyo-glossus muscle and lies between the submaxillary duct and the lingual nerve, apparently suspended from the latter by two short slender filaments. The anterior of these transmits chiefly sympathetic fibres that pass from the ganglion to the lingual nerve, the posterior fibres going from the lingual to the ganglion as its sensory and motor roots.

Roots.—The *sensory root* is contributed by the lingual nerve; the *motor root* proceeds from the facial by way of the chorda tympani and contains secretory fibres; and the *sympathetic root* is derived from the adjoining plexus on the facial artery.

Branches.—The branches of distribution include: (*a*) a number of fibres which pass to the submaxillary gland, (*b*) others which are distributed to the submaxillary duct and the mucous membrane of the floor of the mouth and (*c*) filaments which join

the lingual nerve and, after accompanying it for a short distance, are distributed to the sublingual gland. The sensory fibres, processes of the Gasserian neurones, traverse the submaxillary ganglion without interruption ; the secretory fibres from the facial end, at least in part, around the stellate sympathetic neurones of the ganglion, from which cells axones pass to the alveoli of the submaxillary and sublingual glands ; while other sympathetic filaments proceed, as the axones of stellate cells either within the submaxillary or a more remote sympathetic ganglion, to supply the glandular tissue and ducts, as well as to accompany the peripheral branches of the lingual nerve.

Practical Considerations.—The fifth cranial nerve is the sensory nerve of the face and the motor nerve to the muscles of mastication. It is more frequently the seat of excessively painful neuralgia than any other nerve in the body. Extracranial lesions are much more commonly the cause of such neuralgia than intracranial. The neuralgia is rarely bilateral, and usually does not involve all three divisions of the nerve. It rather attacks one or two divisions, or only a branch of one, the first and second divisions being most frequently involved. Certain tender regions can almost always be found, as over the points of emergence of the nerve on the face, at the supraorbital, infraorbital and mental foramina, where in an interval from pain pressure may produce a paroxysm.

The supraorbital notch or foramen can usually be felt at the junction of the inner and middle thirds of the supraorbital margin. The mental foramen is in the lower jaw, below and between the two bicuspid teeth, while the infraorbital foramen lies just below the lower margin of the orbit in a straight line between the supraorbital and mental foramina.

When the first division is the seat of neuralgia, the disease is almost always confined to the supraorbital branch. Excision of this branch will usually give relief for about two years, sometimes permanently. The same may be said of the infraorbital nerve when the disease is confined to the second division. The infraorbital may be excised at the foramen, through the mucous membrane of the mouth or by an incision in the skin along the lower margin of the orbit. Through the latter the orbital tissues may be raised and the nerve reached farther back in its canal, which in its anterior part has a thin bony covering. By going through the antrum of Highmore from the cheek, just below the infraorbital foramen, the second division, with Meckel's ganglion attached to it may be excised at its emergence from the skull. The anterior wall of the antrum is opened by a trephine or chisel and the floor of the infraorbital canal in the roof of the antrum is gouged away so that the nerve is exposed and followed to the posterior wall of the antrum. This wall is then opened, the spheno-maxillary fossa exposed and the nerve is divided at the foramen rotundum and removed with the ganglion. The bleeding will be severe, since large and numerous branches of the internal maxillary artery surround the ganglion and are divided.

When the neuralgia is confined to the inferior dental nerve the mental branch may be excised at its foramen through the mucous membrane of the mouth. The inferior dental itself is more frequently attacked through a trephine opening in the ascending ramus of the lower jaw. It may with greater difficulty be reached through the mouth, the incision being made along the anterior margin of the descending ramus, and the soft tissues separated from the inner surface of the ramus until the dental spine marking the dental foramen is exposed; the inferior dental nerve and artery will be found entering the canal. The nerve may then be exposed and excised with due regard for the accompanying vessels and the internal maxillary artery, from which the inferior dental branch has just been given off.

The buccal nerve is sometimes the seat of neuralgia, and may be reached by an incision through the cheek in front of the coronoid process and the insertion of the tendon of the temporal muscle. The nerve can be reached from the mouth in the same situation.

When the peripheral operations for trigeminal neuralgia (tic douloureux) have failed to effect a cure, or when the neuralgia primarily shifts from one branch to another, indicating an extensive central involvement, the *Gasserian ganglion* must be

removed or the sensory root resected. The skull is opened in the temporal region and the unopened dura (unless unavoidably torn) is separated inward from the floor of the skull until the ganglion, lying on the apex of the petrous portion of the temporal bone between the two layers of the dura, is exposed and removed. The middle meningeal artery is especially exposed to rupture as it comes through the foramen spinosum. A possible source of even more dangerous hemorrhage, however, is the cavernous sinus, with which the ganglion is intimately associated. Trophic changes in the eye are liable to occur from damage to the first division of the nerve.

The lingual nerve is sometimes divided in painful conditions of the tongue, as in cancer. It is easily reached in the floor of the mouth as it is passing forward to the tongue, just under the mucous membrane. The incision is made about midway between the tongue and the alveolus of the lower jaw.

Paralysis of the sensory branches of the fifth nerve, nontraumatic in origin, is rare, and when it does occur involves usually only individual branches, and these often only in a part of their distribution. When implicating all the divisions of the fifth nerve and associated with pain, it should suggest a tumor of the Gasserian ganglion.

A paroxysmal cough may occur in some patients in whom the respiratory organs are perfectly normal, from irritation of the terminal branches of the trigeminal nerve in the nose, pharynx and external auditory meatus.

THE ABDUCENT NERVE.

The sixth or abducent nerve (**n. abducens**) is exclusively motor and supplies the external rectus muscle of the eyeball. Its **deep origin** is from the *abducent nucleus* (**nucleus n. abducentis**) (Fig. 933), a rounded cluster of multipolar neurones which lies in the dorsal part of the tegmentum of the pons and under the gray matter of the floor of the fourth ventricle. It is situated anterior to the striæ acusticæ, beneath the eminentia teres and ventral to and within the loop formed by the fibres of the facial nerve. Leaving the nucleus on its inner aspect, the root-fibres form several fasciculi which pass backward and ventro-laterally, lying to the inner side of the superior olive. Arriving at the ventral portion of the pons, the major portion of the fibres passes to the outer side of the pyramidal group, a few fasciculi traversing them to reach the surface. The **superficial origin** (Fig. 1046) lies in the sulcus which demarcates the lower edge of the pons from the medulla, a little lateral to the pyramid.

Central and Cortical Connections.—As in the case of the third and fourth nerves, the nucleus of the sixth receives, by way of the posterior longitudinal fasciculus, some of the fibres of the pedicle of the superior olive, thus completing the establishment of a reflex-path between the auditory apparatus and the centres for the nerves controlling the eye-muscles. A second connection is effected by means of the posterior longitudinal fasciculus with the oculomotor nucleus of the opposite side. Finally, the abducent nucleus is brought into relation with the motor area of the cortex by way of the pyramidal tract of the opposite side.

Course and Distribution.—After leaving the surface of the brain-stem, the nerve, which at its superficial origin is flat and often represented by several strands, becomes consolidated and rounded, and bends forward to follow for about 15 mm., the lower surface of the pons. It then pierces the dura mater over the sphenoid bone at a point medial and slightly posterior to the opening for the fifth nerve (Fig 1052). Thence it runs forward through a notch beneath the posterior clinoid process and passes to the outer side of the inferior petrosal sinus and over the apex of the petrous portion of the temporal bone to enter the cavernous sinus. Here it lies somewhat below and to the outer side of the internal carotid artery and, eventually reaching the outer wall of the anterior portion of the sinus, enters the orbit through the sphenoidal fissure, lying above the ophthalmic vein and below the third, fourth and ophthalmic nerves. Leaving the fissure, it passes between the heads of the external rectus muscle, which, after entering its ocular surface, it supplies.

The **communications** of the sixth nerve are: (1) as it traverses the cavernous sinus, filaments from the carotid plexus of the sympathetic and (2) as it enters the orbit, a small sensory filament from the ophthalmic nerve.

Variations.—The nerve may be absent on one side, the external rectus being supplied by a branch from the oculomotor. It may have its superficial origin by several widely separated strands, the accessory fasciculi emerging from between the fibres of the pyramid or through the lower border of the pons.

THE FACIAL NERVE.

The seventh or facial nerve (**n. facialis**) is a mixed nerve and consists of two parts, a larger motor and a smaller sensory. The former supplies with motor fibres the muscles of expression, the extrinsic and intrinsic muscles of the external ear, the stylo-hyoid, the posterior belly of the digastric, the platysma myoides and perhaps also the levator palati and the azygos uvulæ. Certain of the motor fibres are peculiar and as secretory fibres are destined for the supply of the submaxillary and sublingual glands. The sensory part of the facial conveys gustatory fibres to the anterior two-thirds of the tongue.

The **sensory part** is commonly known as the *pars intermedia of Wrisberg* (**n. intermedius**) which, instead of being a distinct nerve, may with propriety be regarded as the sensory portion of the seventh—a view strongly supported upon morphological grounds. The sensory fibres are processes of the cells situated within the

FIG. 1066.

Brain-stem with nuclei of cranial nerves shown diagrammatically; motor nuclei and fibres are blue; sensory nuclei and fibres are red. *a*, oculomotor nerve; *b*, trochlear nerve; *c*, motor part of trigeminal nerve; *d*, sensory part of trigeminal nerve; *e*, spinal root of sensory part of trigeminal nerve; *f*, facial nerve; *g*, abducens nerve; *h*, vestibular portion of auditory nerve; *i*, cochlear portion of auditory nerve; *j*, glosso-pharyngeal nerve; *k*, vagus nerve, showing also the nucleus ambiguus in black; *l*, hypoglossal nerve; *m*, vagus portion of spinal accessory nerve. (*Posey and Spiller.*)

enlargement on the facial nerve known as the *geniculate ganglion*, which is situated within the facial canal at the so-called *knee*. Passing through the proximal part of the facial canal, the axones of the geniculate ganglion cells enter the cranium through the internal auditory meatus, lying above the auditory nerve and below the motor root of the seventh, with both of which they communicate. Leaving the meatus, they pass inward and enter the brain-stem at the **superficial origin**, (Fig. 1046), which is located at the lower border of the pons, between the motor root of the seventh and the auditory nerve.

Entering the substance of the medulla, the sensory fibres pass either through or dorsally to the spinal root of the trigeminal nerve to reach the superior part of the *nucleus of reception*, which it shares with the glosso-pharyngeal and vagus nerves (page 1262). On gaining this nucleus, the sensory fibres divide into short ascending and much longer descending branches, thus behaving in a manner identical with that of the corresponding fibres of the trigeminus and other mixed cranial nerves. The termination of the sensory fibres is around the neurones of the reception-nucleus, from which axones pass to the mesial fillet of the opposite side, and eventually, to the cerebral cortex.

The **motor part** is by far the larger of the two and constitutes both anatomically and functionally the more important portion of the nerve. The **deep origin** of the motor root is from the *facial nucleus* (Fig. 933), an oval collection of some half dozen groups of large multipolar neurones, which measures about 5 mm. in length, and is situated in the posterior portion of the tegmentum of the pons. It lies within the formatio reticularis medial to the spinal root of the trigeminal nerve and, in its lower part, close to the fibres of the corpus trapezoides; higher up it is tilted dorsally and separated from these fibres by the superior olive, to the upper and outer side of which it lies. Although the facial nucleus is situated close to the superficial origin of the seventh nerve, the root-fibres instead of taking a direct route to the ventral surface of the brain-stem follow a devious course. The intracerebral part of the nerve has been divided for convenience of description into a radicular, an ascending and an emergent portion.

The *radicular portion* consists of numerous loose fasciculi of root-fibres which arise from the dorso-lateral aspect of the nucleus of origin and pass backward and slightly inward. The upper fibres stream over the dorso-lateral surface of the nucleus of the abducent nerve and then, with the other fibres of the motor root, bend mesially along the floor of the fourth ventricle. As they near the mid-line they turn sharply upward and assemble to form a solid strand, the *ascending portion* of the seventh nerve. This upward course continues for about 5 mm. and in this situation the nerve is separated from the floor of the fourth ventricle, beneath which it runs within the funiculus teres, only by the lining ependyma and lies immediately dorsal to the posterior longitudinal bundle and mesial to the abducent nucleus. The nerve now bends abruptly outward at a right angle and enters upon the *emergent portion* of its course, during which it crosses the dorsal aspect of the abducent nucleus and passes backward and ventro-laterally, between its own nucleus of origin and the spinal root of the trigeminal nerve, to gain the exterior of the brain-stem (Fig. 1066).

The **central** and **cortical connections** of the motor part of the facial nerve include paths whereby the nucleus is brought under the influence of the reflex and the cortical centres. (*a*) While not beyond dispute, it is probable that a limited number of root-fibres are connected with the facial nucleus of the opposite side. (*b*) The evidence adduced from clinical observations and pathological findings points to the existence of a special group of cells from which arise the fibres supplying the orbicularis palpebrarum and frontalis muscles. These fibres, sometimes called the *superior facial nerve*, may retain their functional integrity notwithstanding the occurrence of paralysis of the other muscles supplied by the seventh nerve. (*c*) The latter, morever, is brought into association with the visual and auditory centres by paths, probably within the posterior longitudinal fasciculus, by which the facial cells respond to the impulses of sight and hearing, as shown by the automatic closure of the eyelids. (*d*) Connection with the hypoglossal nerve has been assumed in explanation of the coördinated action of the muscles of the lips with those of the tongue. (*e*) The motor facial nucleus is brought under the influence of the cortical area by the cortico-bulbar fibres which proceed as axones from the motor neurones lying within the lower part of the precentral convolution. These fibres descend in company with the cortico-spinal tracts to appropriate levels and end around the radicular cells of the facial nucleus of the opposite side, a few fibres, however, probably terminating in the nucleus of the same side.

The **superficial origin** of the motor root is at the lower border of the pons, to which it may be adherent, in a groove between the inferior olive and the inferior cerebellar peduncle (Fig. 1046). Just above the facial as it escapes, often as several strands of root-fibres, lies the fifth nerve and to its outer side is the auditory, from which it is separated by the sensory root of the seventh.

Emerging from the surface of the brain-stem, the nerve passes outward, its motor and sensory roots ununited, to the internal auditory meatus, through which it passes above and anterior to the auditory. At the bottom of the meatus the seventh and eighth nerves part company, the facial entering the facial canal, whose course it follows throughout. At first the canal is directed horizontally outward, between the cochlea and the vestibule, until it reaches the mesial tympanic wall. It then bends abruptly backward, passes above the fenestra ovalis and turns downward, behind the pyramid, in the posterior wall of the tympanic cavity, to end at the stylo-mastoid foramen. The point where the canal turns backward marks a corresponding bend, *the genu*, of the facial nerve. In this situation is found the *geniculate ganglion* and here the two roots fuse to form a single trunk. After emerging from

the stylo-mastoid foramen the nerve passes downward, outward and forward through the parotid gland, and divides, just posterior to the ramus of the mandible, into its terminal branches, the *temporo facial* and the *cervico-facial*. The filaments of these branches freely join with one another and form the fan-like **parotid plexus** (**plexus parotideus**), also called *pes anserinus.*

The **geniculate ganglion** (**g. geniculi**) is a small oval or fusiform thickening on the facial nerve, at the point where it turns backward (**geniculum n. facialis**), and contains unipolar neurones, whose axones form the sensory root of the facial nerve and whose dendrites form the sensory fibres of distribution of the seventh.

The so-called **branches of the geniculate ganglion**—the great and external superficial petrosal nerves and the branches to the tympanic plexus—are only in part composed of fibres connected with the ganglion cells; they are, therefore, more appropriately regarded as branches of the facial nerve.

Branches and Distribution.—Within the facial canal, the facial nerve gives off: (1) the *great superficial petrosal*, (2) the *branch to the tympanic plexus*, (3) the *external superficial petrosal*, (4) the *stapedial*, (5) the *chorda tympani* and

FIG. 1067.

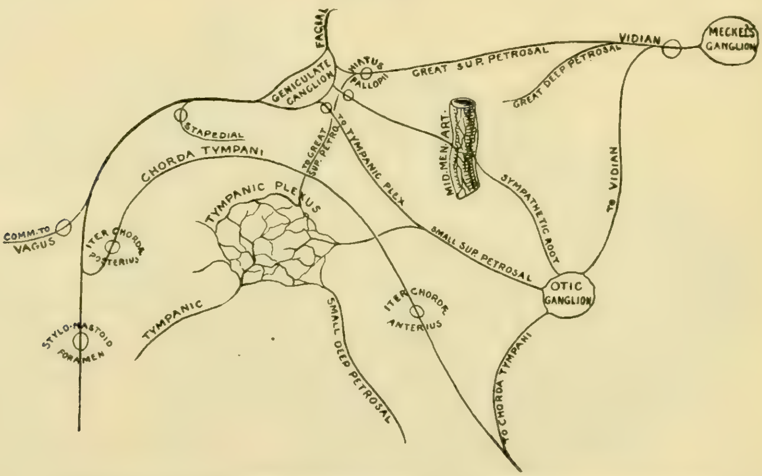


Diagram showing branches and connections of facial nerve within facial canal.

(6) the *communicating branch to the vagus*. The first three are closely connected with the geniculate ganglion. Outside the facial canal arise: (7) the *posterior auricular*, (8) the *digastric*, (9) the *stylo-hyoid*, (10) the *temporo-facial* and (11) the *cervico-facial nerve*. The last two nerves arise in an uncertain manner from that irregular plexiform expansion, known as the **pes anserinus,** into which the facial broadens within the substance of the parotid gland after emerging from the stylo-mastoid foramen.

1. The **great superficial petrosal nerve** (**n. petrosus superficialis major**) (Fig. 1061), while issuing directly from the ganglion, contains motor fibres in addition to the sensory. It leaves the facial canal through the hiatus Fallopii, enters the middle cranial fossa and passes forward under the Gasserian ganglion and over the cartilage of the middle lacerated foramen. The nerve then crosses the outer side of the internal carotid artery to reach the posterior opening of the Vidian canal, where it is joined by the great deep petrosal nerve (page 1360) from the carotid sympathetic plexus, with which it unites to form the *Vidian nerve*. The latter traverses the Vidian canal to the spheno-maxillary fossa and there enters the posterior aspect of the spheno-palatine ganglion, whose motor and sympathetic roots it contributes. The probable relations and destination of these fibres have been considered in connection with the spheno-palatine ganglion (page 1240).

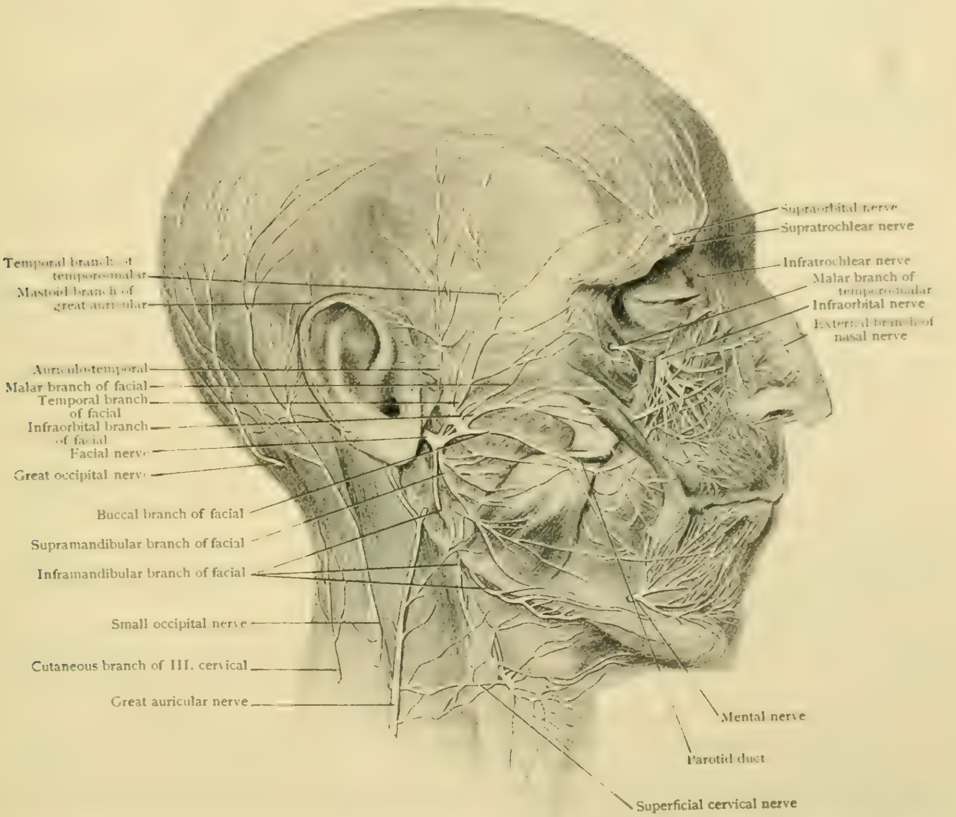
2. The **communicating branch to the tympanic plexus** (**r. anastomoticus cum plexu tympanico**) traverses a tiny canal in the temporal bone to reach the tympanic cavity, where it joins the main continuation of the tympanic plexus of the

glosso-pharyngeal to form the small superficial petrosal and proceeds to the otic ganglion, which it enters as the sensory root (page 1246). The fibres from the tympanic plexus, probably secretory in function, are distributed from the otic ganglion to the parotid gland.

3. The **external superficial petrosal nerve** is very small and is not always present. It joins the sympathetic plexus on the middle meningeal artery.

4. The **stapedial nerve** (**n. stapedius**), for the supply of the stapedius muscle, is given off as the facial passes downward behind the pyramid in the posterior wall of the tympanic cavity, the nerve gaining access to the muscle by passing through a minute orifice in the base of the pyramid.

Fig. 1068.



Superficial dissection of head and neck, showing terminal branches of trigeminal, facial and great occipital nerves, as well as associated branches of cervical plexus.

5. The **chorda tympani nerve** (**n. chorda tympani**), while conveying both motor and sensory impulses, consists mainly of sensory fibres derived from the cells of the geniculate ganglion. It arises from the facial a short distance above the stylo-mastoid foramen and courses upward and forward through the iter chordæ posterius to enter the tympanic cavity (Fig. 1067). Passing between the fibrous and mucous layers of the membrana tympani, over the tendon of the tensor tympani and between the long processes of the incus and malleus, it arrives at the anterior edge of the membrane. It then traverses the iter chordæ anterius to reach the pterygo-maxillary region, and, after receiving a filament from the otic ganglion, takes a course downward and forward, after which, under cover of the external pterygoid muscle, it unites and becomes incorporated with the lingual branch of the mandibular nerve. As the latter passes above the submaxillary ganglion, the motor fibres of the chorda tympani (facial) descend to the ganglion as its motor root and probably eventually end as secretory fibres to the submaxillary and sublingual glands. The sensory

fibres of the chorda tympani, on the other hand, are distributed to the mucous membrane covering the anterior two-thirds of the side and dorsum of the tongue, and are probably concerned in transmitting taste-impulses.

6. The **communicating branch to the auricular branch of the vagus** (**r. anastomoticus c. ramo auriculari n. vagi**) is given off just above the stylo-mastoid foramen and joins the auricular at the point where the latter crosses the facial canal.

7. The **posterior auricular nerve** (**n. auricularis posterior**) arises just outside the stylo-mastoid foramen. It passes backward and upward between the external ear and the mastoid process and divides into (*a*) an *occipital branch*, which supplies the occipitalis muscle and (*b*) an *auricular branch*, which supplies the posterior auricular muscle, often partially the superior, and the transversus, the obliquus and the antitragicus of the intrinsic muscles of the auricle.

The posterior auricular nerve **communicates** with the auricular branch of the vagus, the small occipital and the great auricular nerve.

8. The **digastric branch** (**r. digastricus**) arises from the facial below the posterior auricular nerve and breaks up into several filaments which enter the posterior belly of the digastric. One of these filaments, after passing through or above the digastric, may join the glosso-pharyngeal nerve.

9. The **stylo-hyoid branch** (**r. stylohyoideus**) is a small twig which arises in common with the digastric branch and passes forward to enter the posterior portion of the stylo-hyoid muscle.

10. The **temporo-facial division** (**r. temporofacialis**) (Fig. 1087) is the larger of the two terminal branches. It traverses the upper portion of the parotid gland in a forward and upward direction, lying superficial to the external carotid artery and the temporo-maxillary vein. By repeated branchings and unions the nerve forms an intricate looped plexus which breaks up into three more or less definite groups.

Branches.—These are: (*a*) the *temporal*, (*b*) the *malar* and (*c*) the *infraorbital*.

a. The *temporal branches* (**rr. temporales**) pass upward and forward over the zygomatic arch and supply the frontalis, the corrugator supercilii, the upper part of the orbicularis palpebrarum, the auricularis superior and the auricularis anterior.

The temporal branches of the facial **communicate** with the following branches of the trigeminal: the auriculo-temporal, the supraorbital, the lachrymal and the temporal branch of the temporo-malar.

b. The *malar branches* (**rr. zygomatici**) are rather small. They extend forward over the malar bone and are sometimes incorporated with the temporal or infraorbital branches. They supply the lateral part of the orbicularis palpebrarum and sometimes the zygomatici major et minor.

The malar branches **communicate** with the malar branch of the temporo-malar.

c. The *infraorbital branches* (**rr. buccales superiores**) are comparatively large. They course horizontally forward across the masseter muscle in company with the parotid duct and supply the lower part of the orbicularis palpebrarum, a portion of the buccinator, the zygomatici major et minor and the muscles of the nose and upper lip.

The most important of the **communications** is the one between the infraorbital and the terminal branches of the maxillary division of the trigeminal. This is a sensory-motor plexus which lies below the infraorbital foramen and under the levator labii superioris and is called the *infraorbital plexus* (Fig. 1068). The nasal and infratrochlear nerves communicate with the infraorbital at the side of the nose.

11. The **cervico-facial division** (**r. cervicofacialis**) (Fig. 1087) is the smaller of the terminal branches of the facial and resembles in its general arrangement the temporo-facial. It passes downward, outward and forward through the parotid gland and finally breaks up into three branches.

Branches.—These are: (*a*) the *buccal*, (*b*) the *supramandibular* and (*c*) the *inframandibular*.

a. The *buccal branch* (**rr. buccales**) may be single or multiple. It crosses the masseter and supplies the buccinator and orbicularis oris muscles.

It **communicates** on the outer surface of the buccinator muscle with the sensory buccal branch of the mandibular division of the trigeminal nerve.

b. The *supramandibular branch* (r. marginalis mandibularis) passes forward between the lower lip and the chin and supplies the muscles of the lower lip.

Its filaments communicate with those from the mental branch of the inferior dental.

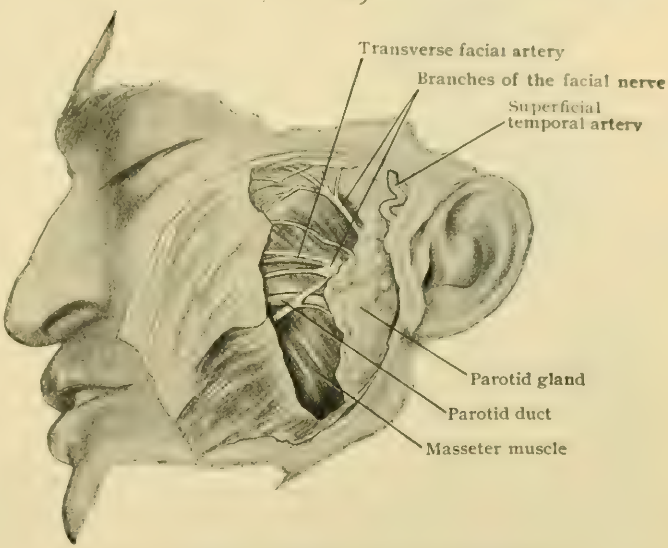
c. The *inframandibular branch* (r. colli) emerges from the lower margin of the parotid gland and takes a downward course behind the angle of the jaw. Piercing the deep cervical fascia, it passes forward in the neck and forms a series of loops beneath the platysma myoides as far down as the hyoid bone. It supplies the platysma myoides.

The nerve communicates with the superficial cervical branch of the cervical plexus.

Practical Considerations.—The facial nerve may be the seat of spasm (tic convulsif) or of paralysis. The lesion may be central or peripheral, the latter being more common. When the spasm is confined to certain branches it usually involves the muscles about the eyes. If only the orbicularis is involved it is called *blepharospasm*; if the adjacent muscles also are involved, *spasmus nictitans*. The facial nerve is more frequently associated with spasm than any other in the body, except the spinal accessory.

Facial paralysis is relatively common. If the *central* lesion—as a tumor, abscess or hemorrhage—is limited to the facial centre in the cortex, a monoplegia of the facial nerve will result, and the paralysis will usually be confined to the lower branches of the nerve in the face and neck, the upper branches escaping probably because of bilateral innervation of the upper muscles of the face. A cortical isolated paralysis of this type is exceedingly uncommon. If the lesion, as an apoplectic hemorrhage, is in the internal capsule, a hemiplegia on the same side as the facial paralysis will be associated with it, and this also usually occurs when the lesion is cortical. A lesion in the upper part of the pons will give rise to a similar condition, but if it is in the middle or lower part of the pons the facial nerve will be paralyzed on the side of the lesion, the hemiplegia being on the opposite side (crossed paralysis). This is explained by the fact that the facial fibres cross to the opposite side in the pons, while the motor fibres to the extremities and trunk cross in the medulla. A lesion in the middle or lower part of the pons on one side, therefore, will involve the facial fibres after they have crossed, and the motor fibres to the extremities before they have crossed. Thus the facial nerve will be paralyzed on the side of the lesion, and there will be a hemiplegia of the opposite side.

FIG. 1069.



Dissection showing relations of facial nerve branches as they cross masseter muscle.

The peripheral portion of the facial extends from its exit at the pons to its terminal filaments on the face, but a lesion of the facial nucleus in the pons gives rise to much the same symptoms as one of the nerve at its exit from the pons. Its intracranial portion may be involved by tuberculous deposits, tumors, etc. In its long course through the Fallopian canal it may be affected by swelling of the soft tissues, by middle ear disease, or by fractures of the base of the skull in the middle fossa. After it leaves the stylo-mastoid foramen it is in greatest danger, as from exposure to atmospheric influences, and to accidental and operative wounds. It is especially apt to be wounded in that portion which lies within the parotid gland.

When all branches of the facial are paralyzed the symptoms are characteristic. Only one side of the forehead wrinkles ; the tears fail to enter the canaliculi, and flow over the cheek ; the eye cannot be closed ; foreign bodies on its surface are not removed by the lid, and conjunctivitis from irritation results. The affected half of the face is expressionless, and the corner of the mouth on that side remains partly open and hangs down, so that the saliva tends to run out. The mouth is drawn to the opposite side ; the upper lid cannot be elevated ; whistling is impossible because the orbicularis cannot now pucker the lips ; food lodges in the affected side of the mouth, because the buccinator muscle is paralyzed, and, for the same reason, the mucous membrane often gets caught between the teeth.

In those cases of facial paralysis in which the lesion of the nerve is posterior to the stylo-mastoid foramen, attempts have been made recently to restore function to the peripheral portion by dividing the trunk posterior to the parotid gland, and anastomosing the peripheral end to a neighboring cranial nerve, as the spinal accessory or the hypoglossal. The results have not been entirely satisfactory.

The line of the main trunk of the nerve is from the slight depression between the back of the ear and the mastoid process, forward and slightly downward. It passes through the deeper portion of the parotid gland.

THE AUDITORY NERVE.

The eighth or auditory nerve (**n. acusticus**) is not only, as its name implies, the nerve by which sound impulses are transmitted to the brain, but also the nerve of equilibration. It consists of two portions, the *cochlear*, the true nerve of hearing, and the *vestibular*, which is concerned with equilibration.

Traced from the brain toward the ear, the auditory nerve arises at its **superficial origin** by two roots, a mesial (**radix vestibularis**) and a lateral (**radix cochlearis**), which embrace the inferior cerebellar peduncle, the mesial passing to the inner and the lateral to the outer side of the peduncle. The nerve thus formed by the union of these two roots, leaves the surface of the brain-stem at the posterior border of the pons, where it is adherent to the middle cerebellar peduncle. To its inner side and closely associated with it are the motor and sensory roots of the facial nerve (Fig. 1046), which lie within a groove on the mesial surface of the auditory and with it enter and traverse the internal auditory canal. Within the latter, the auditory nerve separates into two divisions, of which the superior and larger is the **vestibular nerve** (**n. vestibuli**) and the inferior and smaller is the **cochlear nerve** (**n. cochleae**). Although in a general way these divisions continue the corresponding roots, this agreement, as to the source of their fibres, is not complete, since, as will be more fully noted, strands of vestibular fibres are incorporated with the cochlear nerve.

On reaching the bottom of the internal auditory canal, the facial nerve leaves the meatus and enters the facial canal, while the fibres of the auditory nerve disappear through apertures in the lamina cribrosa (Fig. 201) to gain the several parts of the membranous labyrinth of the internal ear. During their journey through the meatus, the vestibular and facial trunks are connected (**fila anastomica**) by a branch which passes from the pars intermedia to the vestibular nerve, and by one from the latter to the geniculate ganglion. These apparent communications between the seventh and eighth nerves are, in fact, only aberrant strands of facial fibres that return to the seventh after temporary association with the auditory.

The **vestibular nerve** divides into three terminal branches which pass through apertures in the cribriform plate above the falciform crest and supply: (1) the *utricle*, (2) the *superior* and (3) the *external semicircular canal*. Not all the fibres of the vestibular root, however, are included in these branches ; of the three branches given off by the cochlear nerve two, (4) those to the *saccule* and (5) to the *posterior semicircular canal*, are vestibular fibres incorporated with the cochlear, although seemingly derived from the cochlear nerve. The remaining branch of the **cochlear nerve** contains the cochlear fibres proper, which traverse the numerous foramina of the tractus spiralis foraminosus and the central canal of the modiolus to supply the organ of Corti within the membranous cochlea.

Although the auditory nerve as a whole may be conveniently followed from the brain to the ear, as has been done in the preceding sketch, it is evident since its fibres are sensory and therefore afferent, that they are the processes (axones) of nerve-cells situated somewhere along the course of the nerve. It is necessary, consequently, to seek the real origin of these fibres in the ganglia occurring on the divisions of the nerve. In recognition of the functional differences of the two roots of the eighth nerve, it is desirable to trace separately the pathway followed by the impulses conveyed by each of these components.

FIG. 1070.

Reconstruction of left membranous labyrinth of human embryo of ten weeks (30 mm.), lateral aspect; vestibular nerve and ganglion are red; cochlear nerve is blue; vestibular rami are seen passing to ampullæ of semicircular canals and to maculæ of utricle and saccule. × 20. (*Streeter.*)

Peripheral, Central and Cortical Connections of the Cochlear Nerve.—The true cochlear fibres arise within the internal ear (cochlea) as axones of the cells of the **spiral ganglion** or *ganglion of Corti* (**g. spirale**) (Fig. 1071). This structure consists of a series of bipolar neurones which occupies the spiral canal in the base of the lamina spiralis. The dendritic processes of these cells begin as fine fibrils which lie in close relation with the neuroepithelial cells comprising the inner and outer hair-cells of the organ of Corti. Leaving the hair-cells as nonmedullated fibres, they traverse the foramina nervosa of the labium tympanicum, at which point they become medullated. They then interlace to form an elaborate flat felt-work that lies between the layers of the lamina spiralis and soon assembles to form bundles which pass to the cells of the ganglion spirale, each fibre probably joining its individual cell. Leaving the ganglion, the axones of its cells enter the bony canals within the modiolus, from which they emerge at the tractus spiralis foraminosus and are collected into a single bundle, the cochlear nerve proper. The latter, however, soon receives two accessions, one of which consists of fibres from the saccule and the other from the posterior semicircular canal. From what has been said, it is evident that these accessions are parts of the vestibular nerve and, beyond their temporary companionship, have nothing to do with the cochlear root.

On reaching the medulla, the cochlear fibres come into relation with their nucleus of reception, which includes two superficial aggregations of nerve-cells that collectively constitute the **acoustic nucleus** (**nucleus acusticus**). The latter consists of two parts (Fig. 932) of which one, the **ventral cochlear nucleus**, also called the *accessory acoustic nucleus* (**nucleus accessorius**), lies ventral to the inferior cerebellar peduncle, and the other, the **lateral cochlear nucleus**, or **tuberculum acusticum**, rests upon the dorso-lateral surface of the peduncle and occupies the extreme outer part of the triangular acoustic area seen in the lateral angle of the floor of the fourth ventricle (page 1097). The greater number of cochlear fibres end in arborizations around the stellate cells of the ventral ganglion, while others terminate in relation with the more elongated, fusiform cells of the lateral nucleus. From the neurones of these subdivisions of the reception nucleus, the auditory pathway is continued as two chief tracts, the axones of the cells of the ventral nucleus passing for the most part ventral to the restiform body and the spinal root of the trigeminus to form the *corpus trapezoides*, while those from the lateral nucleus sweep around the outer surface of the restiform body and then medially beneath the ependyma of the floor of the fourth ventricle, where they show with varying degrees of distinctness as the *acoustic striæ* (Fig. 918).

The **corpus trapezoides**, the conspicuous transverse tract that separates the tegmental from the ventral region of the pons in its superior part, is formed chiefly by the axones of the cells within the ventral cochlear nucleus, supplemented by a limited number of fibres that spring from the lateral nucleus. In addition it contains axones from the large cells found within the trapezoid body, on each side of the mid-line, that constitute the **nucleus trapezoideus**. In close relation with the dorsal surface of the corpus trapezoides, within the superior olive and on either side of the median raphe, lies the **superior olivary nucleus** (**nucleus olivaris superior**), a collection of nerve-cells around which many of the cochlear fibres, chiefly from the opposite but also from the same side, end and from which the tract of the **lateral fillet** principally takes

origin (Fig. 1071). Not all of the fibres arising from the superior olivary nucleus, however, enter the lateral fillet. A considerable number leave the dorsal surface of the nucleus and, as its *peduncle*, pass to the abducent nucleus and, by way of the posterior longitudinal fasciculus, to the nuclei of the other eye-muscle nerves. In this manner reflex paths are established by which the motor nerves, including probably the facial, are brought under the influence of auditory impulses. Within the tract of the fillet and a short distance beyond the superior olive, is encountered a group of nerve-cells, the **nucleus of the lateral fillet** (**nucleus lemnisci lateralis**). While numerous additions to the fillet are received from these cells, their relation to the cochlear fibres is uncertain. The characteristics, course and destination of the lateral fillet have been elsewhere described (page 1082). Suffice it here to recall that, so far as the auditory fibres are concerned, the tract terminates chiefly in the inferior colliculus of the quadrigemina and the median geniculate body.

In addition to its constituents through the corpus trapezoides, the lateral fillet receives considerable accessions of cochlear fibres by way of the **striæ acusticæ**. These strands consist of the axones, for the most part, of the cells lying within the tuberculum acusticum, but to a limited

Fig. 1071.

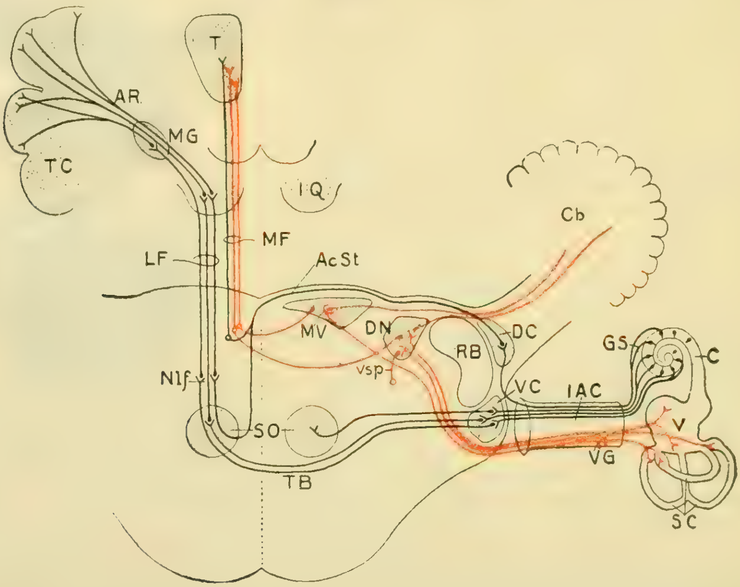


Diagram showing connections of auditory nerve; cochlear fibres and connections are in black, vestibular in red; *C*, cochlea; *GS*, ganglion spirale; *IAC*, internal auditory canal; *VC*, *DC*, ventral and dorsal cochlear nuclei; *RB*, restiform body; *SO*, superior olive; *TB*, trapezoid body; *Ac St*, acoustic striæ; *Nlf*, nucleus of lateral fillet (*LF*); *MF*, median fillet; *IQ*, inferior quadrigeminal body; *MG*, median geniculate body; *AR*, auditory radiation; *TC*, temporal cortex; *T*, thalamus; *SC*, semicircular canal; *V*, vestibule; *VG*, vestibular ganglion; *MV*, median vestibular nucleus; *DN*, lateral (Deiters') vestibular nucleus; *Vsp*, vestibulo-spinal fibre; *Cb*, cerebellum.

extent also of the axones of the ventral cochlear nucleus, which wind over the latero-dorsal surface of the inferior cerebellar peduncle, pass medially beneath the ependyma of the floor of the fourth ventricle as far as the median groove, and, crossing to the opposite side, then sweep ventrally through the dorsal region of the medulla or pons to join the tract of the lateral fillet, and so proceed in company with the other cochlear fibres to the higher levels. By no means all of the component fibres of the acoustic striæ follow the lateral fillet, since some after decussation turn brainward, possibly joining the mesial fillet, whilst others may enter the posterior longitudinal fasciculus to assist in establishing reflex paths influencing the motor nerves.

The **auditory path**, by which the impulses gathered from the organ of Corti by the cochlear fibres are conducted to the cerebral cortex, includes the following components (Fig. 1071):

1. Peripheral neurones of the ganglion spirale, whose axones (the cochlear fibres) pass to the reception-nucleus (ventral and lateral cochlear nuclei).

2. Neurones of the cochlear nuclei, which send their axones: (*a*) by way of the corpus trapezoides to the superior olivary nucleus, chiefly to that of the opposite side but also to that of the same side, or to the lateral fillet or its nucleus without interruption in the olive; (*b*) by way of the striæ acusticæ through the tegmentum to join the trapezoidal fibres.

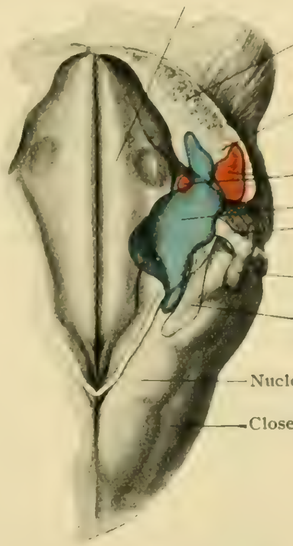
3. Neurones of the superior olivary nucleus or of the fillet-nucleus, whose axones pass by way of the lateral fillet (*a*) to the cells within the inferior colliculus, or (*b*) without interruption through the inferior brachium to the cells within the median geniculate body.

4. Neurones of the inferior colliculus and of the median geniculate body, whose axones pass, as the *auditory radiation*, to the auditory cortical area within the temporal lobe of the cerebrum. Although the exact extent of the auditory area is still uncertain, the most important part of this centre includes the superior temporal and the subjacent part of the middle temporal convolution.

The cochlear fibres that do not undergo decussation ascend through the lateral fillet of the same side and eventually establish cortical relations with the corresponding hemisphere; from the preceding account, however, it is manifest that the auditory area is connected chiefly with the cochlea of the opposite side.

Peripheral, Central and Cortical Connections of the Vestibular Nerve.—The fibres of the vestibular portion of the auditory nerve are the axones of the bipolar nerve-cells situated within the small **vestibular ganglion** (**g. vestibulare**) or *Scarpa's ganglion*, which lies at the bottom of the internal auditory canal. The dendrites of these cells constitute the five branches of distribution of the vestibular nerve and pass through the various openings in the inner wall of the bony labyrinth, in the manner above described (page 1256), to reach the specialized areas, the *maculæ acusticæ*, within the saccule, the utricle and the ampullæ of the semicircular canals, where the nerve-filaments end, really begin, in intimate relation with the neuro-epithelium. While the centrally directed axones of the neurones supplying the utricle and the superior and external semicircular canals become consolidated to form the vestibular nerve of descriptive anatomy, those from the saccule and the posterior semicircular canal join the cochlear fibres and with these course within the cochlear nerve until the latter and the vestibular nerve unite to form the common auditory trunk. Where the common trunk separates into the two roots, the vestibular fibres leave the cochlear and permanently assume their natural companionship with the remaining fibres of the vestibular root.

FIG. 1072.



Vestibular nuclei as shown in reconstruction by Dr. Florence R. Sabin.

The vestibular fibres enter the brain-stem at a slightly higher level than does the cochlear root, lying mesial to the latter and the ventral cochlear nucleus, and pass dorsally within the pons between the inferior cerebellar peduncle and the spinal trigeminal root. On reaching a level dorsal to the latter, the vestibular fibres divide into short upward and longer downward coursing branches, which, after condensing into an ascending and a descending root respectively, end in arborizations around the cells of the **vestibular nucleus of reception.** The exact extent and constitution of this nucleus, which underlies the area acustica in the floor of the fourth ventricle (page 1097), are uncertain, since the neurones directly related to the vestibular fibres contribute only a part of those contained within a large diffuse complex of cells and fibres, many of whose constituents probably have only an indirect connection with the vestibular nerve. When reconstructed, as has been successfully done by Sabin, this complex has the form shown in Fig. 1072 and comprises two general parts, (*a*) an extended irregularly triangular mass of cells lying for the most part mesial to the tract formed by the ascending and descending branches of the vestibular fibres, and (*b*) a smaller mass of cells which lies above the larger one and partly to the inner and partly to the outer side of the tract of the vestibular fibres. The apex of the large triangular mass approaches the mid-line and its superior and inferior basal angles are prolonged upward and downward along the vestibular tract.

When examined microscopically the large mass is found to include three subdivisions: (*a*) a tapering caudally directed nucleus which continues the inferior angle along the descending vestibular root, (*b*) an extended triangular nucleus that includes the greater part of the large mass and (*c*) an irregular pyramidal nucleus that prolongs upward the superior angle. The first of these subdivisions (*a*) is known as the **spinal vestibular nucleus** (**nuc. spinalis n. vestibularis**), the second (*b*) as the **median vestibular nucleus** (**nuc. medialis n. vestibularis**), also as the *chief nucleus* or the *triangular nucleus* and the third (*c*) as the **superior vestibular nucleus** or the

nucleus of Bechterew. The small mass corresponds with the **lateral vestibular nucleus** (nuc. lateralis n. vestibularis) or **nucleus of Deiters**. The fibres of the descending root end around the neurones within the spinal nucleus in a manner similar to that in which the constituents of the spinal root of the trigeminus terminate in relation with the neurones within the substantia gelatinosa, whilst those of the ascending vestibular root end around the cells within the remaining vestibular nuclei.

Although much uncertainty and conflict of opinion exist as to the details of the secondary paths by which the impulses carried by the vestibular fibres are distributed, it may be accepted as established that fibres pass from the nuclei of reception: (*a*) to the cerebellum (chiefly to the roof nucleus of the opposite side and, possibly, also to the nuclei globosus and emboliformis) as constituents of the nucleo-cerebellar tract, by which the impulses of equilibration are carried to the great coördinating centres, (*b*) as arcuate fibres ventro-medially into the tegmentum of the pons, cross the mid-line and bend upward or downward to pass to other levels, some fibres, however, remaining on the same side. From the character of the impulses it is probable that only relatively few vestibular fibres join the median fillet to ascend to the optic thalamus. Other connections of the nuclei include: (*c*) commissural fibres between Bechterew's nucleus of the two sides, (*d*) fibres to the abducent nucleus, (*e*) crossed and uncrossed fibres from Deiters' nucleus to the posterior longitudinal fasciculus and (*f*) fibres from the same nucleus to the spinal cord.

It must be understood that by no means all of the neurones of Deiters' nucleus are concerned in transmitting afferent impulses to the cerebellum, for, as a matter of fact, many are links in the path by which the cerebellar cells exercise coördinating influences over the root-cells of the spinal nerves. Starting in the cerebellum, such efferent impulses are carried by efferent fibres which descend through the median part of the inferior cerebellar peduncle and probably end around certain of the cells within Deiters' nucleus. From these cells, in turn, originate the fibres of the vestibulo-spinal tract, which, after traversing the medulla, enter the antero-lateral column of the cord and end in relation with the motor root-cells. A shorter and more direct path for vestibular reflexes is probably formed by the collaterals of the vestibular fibres that end around the spinal neurones of Deiters' nucleus. It must not be forgotten that Deiters' nucleus is the origin for important contributions to the posterior longitudinal fasciculus (page 1117), by which the vestibular impulses impress the nuclei of the motor and, perhaps to a limited degree, also those of the sensory nerves.

Practical Considerations.—The auditory nerve is rarely the seat of primary disease. It is most frequently affected consecutively to disease of the middle and internal ears. It is sometimes, though seldom, paralyzed in fractures of the base of the skull. Operations on this nerve have been performed for relief from persistent and annoying tinnitus.

THE GLOSSO-PHARYNGEAL NERVE.

The ninth or glosso-pharyngeal nerve (**n. glossopharyngeus**) is a mixed nerve, containing motor and sensory fibres, the latter including those transmitting the impulses of the special sense of taste. The motor element is quite small and supplies only the stylo-pharyngeus muscle and secretory fibres to the parotid gland, while the sensory fibres are distributed to the mucous membrane of the middle ear, fauces, tongue and pharynx.

The Nuclei of the Glosso-Pharyngeal, Vagus and Accessory Nerves.—In the description of the medulla (page 1073) attention was called to the presence of nuclei common to a greater or less extent to the series of lower lateral nerves including the seventh, ninth, tenth and vagal part of the eleventh, which, with the exception of the last named, are mixed nerves. The motor fibres of these nerves differ from those of the series of median motor nerves—the third, fourth, sixth and twelfth—(*a*) in the more lateral situation and less compact grouping of their cells of origin and (*b*) in the less direct course they follow to reach the surface of the brain. To avoid repetition, the general arrangement and characteristics of the nuclei related to the glosso-pharyngeal, vagus, and accessory part of the eleventh nerve will be here described.

The Motor Nuclei.—These include the root-cells within the *dorsal nucleus* and those constituting the *nucleus ambiguus*. The **dorsal nucleus** (**nucleus dorsalis**), a nucleus both of origin and of reception for the fibres of the ninth and tenth nerves, is a narrow elongated tract of nerve-cells, whose upper three-fourths underlies the floor of the fourth ventricle, stretching from the striæ acusticæ above to the tip of the ventricle below, and whose lower fourth extends into the closed part of the

medulla to the level of the nucleus gracilis. It lies immediately lateral to the lower part of the median vestibular nucleus and the upper part of the hypoglossal nucleus, its upper third being covered by the spinal vestibular nucleus and its lower third overlying the hypoglossal nucleus. Its middle third corresponds to the *fovea vagi* (Fig. 949) and comes into intimate relation with the ventricular floor. When examined in cross-sections (Fig. 928) the nucleus appears prismatic in outline and is seen to consist of subgroups of cells, of which the median contains the larger and more conspicuous elements and corresponds to the **dorsal motor nucleus.** The remaining groups, the **dorsal sensory nucleus,** are composed for the most part of small irregular and often spindle cells, that receive end arborizations of afferent fibres.

The **nucleus ambiguus** (**nucleus ventralis**) consists of an ill-defined slender column of large multipolar cells, which extends from the level of the entrance of the cochlear nerve at the upper border of the medulla to about the level of the beginning of the pyramidal decussation, and is best developed in its upper part. In transverse sections of the medulla (Fig. 927), the tract is distinguishable within the formatio reticularis grisea, midway between the dorsal accessory olivary nucleus and the substantia gelatinosa, as a small and inconspicuous group of cells. Arising as axones of the latter, the loosely grouped motor fibres at first pass dorsally to the vicinity of the ventricular floor, then bend sharply outward, and, as in the case of the vagus, join with the similar fibres proceeding from the dorsal motor nucleus to form the emergent root strands.

Fig. 1073.

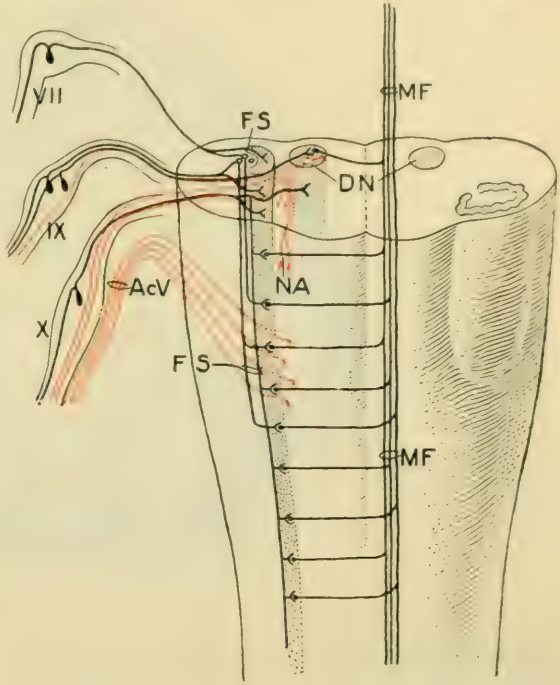


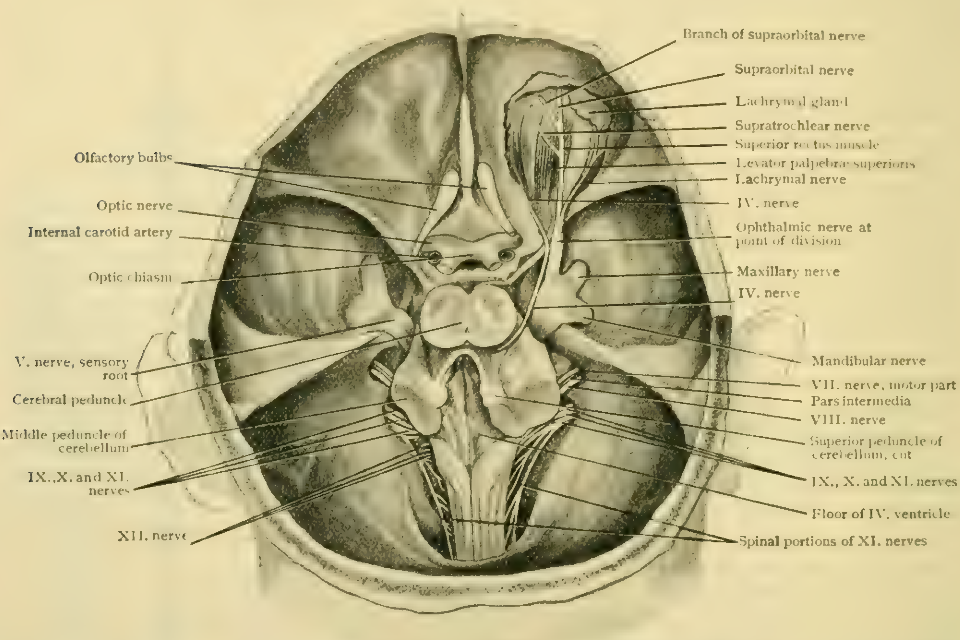
Diagram showing connections of root-fibres of glosso-pharyngeal and pneumogastric nerves and of sensory fibres of facial; sensory fibres are black, motor ones red; *VII*, geniculate ganglion; *IX*, *X*, ganglia of ninth and tenth nerves; *DN*, dorsal nucleus; *FS*, fasciculus solitarius, accompanied by column of gray matter; *NA*, nucleus ambiguus; *AcV*, accessory vagus (bulbar portion of *XI*); *MF*, median fillet.

The Sensory Nuclei.—The nuclei receiving the afferent fibres of the lateral mixed nerves in question include the sensory part of the **dorsal nucleus** (**nucleus alae cinereae**), above described, and a tapering column of gray matter, the **spinal nucleus** (**nucleus tractus solitarii**), which resembles the corresponding nucleus of the trigeminus. The spinal nucleus is closely associated with a conspicuous longitudinal tract of caudally directed fibres, the **fasciculus solitarius** (**tractus solitarius**), so called on account of the apparent isolation of the bundle when viewed in transverse sections (Fig. 927). That such, however, is not the case is evident when the fact is recalled that the fibres which turn downward to form the tract are accompanied by the spinal nucleus of reception, around whose cells they end. The fasciculus solitarius extends from the upper border of the medulla to the level of the lower limit of the decussation of the fillet and is related to the sensory fibres of three nerves. The first of these, the facial, contributes only a limited number of fibres that occupy the uppermost part of the bundle; the second, the glosso-pharyngeal, forms by far the largest constituent of the fasciculus; whilst the third, the vagus, adds fibres that course within the lowest segment of the tract.

Central and Cortical Connections of the Motor Part of the Glosso-Pharyngeal Nerve.—The motor fibres of the glosso-pharyngeal nerve are the axones of the motor neurones situated

within the **dorsal nucleus** and the **nucleus ambiguus.** The fibres proceeding from the dorsal nucleus are distributed to involuntary muscle ; hence the nucleus is sometimes called the *sympathetic motor*. Those taking origin from the nucleus ambiguus supply voluntary muscle and pass at first toward the floor of the fourth ventricle ; they then abruptly change their direction by bending outward and, joining the fibres arising from the dorsal motor nucleus, proceed ventro-laterally through the gray reticular formation, just ventral to or across the spinal root of the trigeminus, to emerge at their superficial origin along the bottom of the postolivary sulcus, incorporated with the afferent fibres in the five or six root-fasciculi forming the entire ninth nerve. The **cortical connections** of the motor fibres are established by cortico-bulbar fibres that arise from cells situated within the gray matter of probably the lower part of the precentral gyrus. After traversing the motor path through the corona radiata, internal capsule, cerebral peduncle and pons, the cortical fibres end, on reaching the upper level of the medulla, in arborizations around the motor root-cells chiefly of the opposite side.

FIG. 1074.



Interior aspect of base of skull, viewed from above and behind, showing particularly posterior group of cranial nerves passing from brain-stem to points of emergence through dura ; posterior part of skull has been removed.

Central Connections of the Sensory Part of the Glosso-Pharyngeal Nerve.—The afferent or sensory fibres of the glosso-pharyngeal nerve are the axones of cells within the **jugular** and **petrous ganglia** situated along the upper part of the nerve-trunk. Entering the skull through the jugular foramen, the sensory fibres approach the brain-stem in the five or six delicate root-bundles that reach the medulla along the groove between the olivary eminence and the inferior cerebellar peduncle. Passing to the ventral side of the spinal root of the trigeminus, or traversing this field, in company with the motor fibres, the afferent fibres continue dorso-mesially through the formatio reticularis grisea towards the dorsal nucleus. Just before reaching the latter, however, the sensory fibres separate into two groups, a *medial* and a *lateral*. The first and smaller of these continues its course to the **dorsal sensory nucleus**, around the cells of which its fibres end. It is possible that the cells constituting the upper groups of the dorsal sensory nucleus are particularly concerned in receiving the impulses giving rise to gustatory impressions, since the glosso-pharyngeal is recognized as the nerve of taste. Considering the fact that the afferent fibres of the facial nerve, which constitute the pars intermedia of Wrisberg, are distributed peripherally chiefly by the chorda tympani, are also concerned in conveying taste-impulses and end, in part at least, in the same nucleus as does the ninth, the sensory portion of the seventh nerve may be regarded, at least functionally, if not from a morphological standpoint, as an aberrant strand of the glosso-pharyngeal.

The second and much larger group turns outward and abruptly downward to form the chief constituent of the spinal tract, the **fasciculus solitarius**. In transverse sections (Fig. 927) the latter appears as a conspicuous, compact, rounded bundle, that lies lateral to the dorsal nucleus and behind the strands of root-fibres. The solitary fasciculus is accompanied throughout its course by a slender column of gray matter, which lies partly on the surface of the bundle and partly amongst its fibres and contains numerous nerve-cells of small size which constitute the reception-station for the greater number of the afferent fibres of the ninth nerve. Since these fibres are continually ending at different levels in their descent, it follows that both the fasciculus and its nucleus gradually diminish in size, until, at about the level of the sensory decussation, they are no longer distinguishable.

Course and Distribution.—Leaving the superficial origin along the groove separating the olivary eminence from the inferior cerebellar peduncle, the isolated root-fasciculi, about half a dozen in number and in series with those of the vagus, assemble to form a single trunk, which passes outward in front of the flocculus of the cerebellum to the jugular foramen. As it traverses this foramen, the glosso-pharyn-

FIG. 1075.

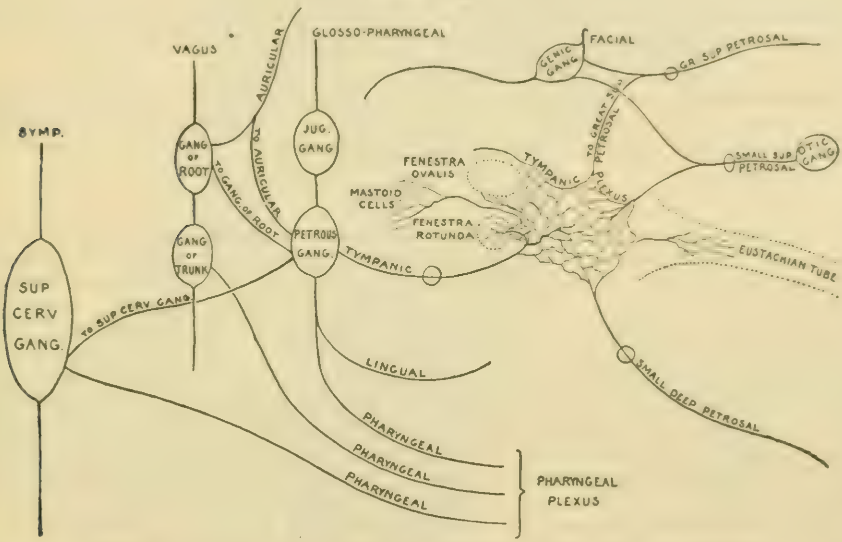


Diagram showing tympanic plexus and connections of glosso-pharyngeal nerve.

geal lies external and anterior to the tenth and eleventh nerves and in its own separate dural sheath. It occupies a groove, or sometimes a bony canal, in the foramen and in this situation presents two thickenings, the *jugular* and *petrous ganglia*. Emerging from the foramen, the nerve passes between the internal carotid artery and the internal jugular vein and, dipping beneath the styloid process, follows a downward course along the posterior border of the stylo-pharyngeus muscle, with which it passes between the internal and external carotid arteries. Turning gradually forward, it reaches the outer side of the stylo-pharyngeus muscle and stylo-hyoid ligament and disappears beneath the hyo-glossus muscle to break up into its terminal branches to the tongue (Fig. 1079).

Ganglia of the Glosso-Pharyngeal Nerve.—In the course of the nerve two ganglia are found, the *jugular* and the *petrous*. They contain aggregations of neurones whose dendrites constitute the peripheral sensory fibres and whose centrally directed axones form the sensory root-fibres of the nerve.

The **jugular ganglion** (g. superius) which may be regarded as a detached portion of the petrous ganglion, lies in the upper part of the groove occupied by the glosso-pharyngeal nerve in its transit through the jugular foramen. It is variable in size and not always present and measures only from 1–2 mm. in length. The ganglion does not include the entire thickness of the nerve but only the inferior portion, the fibres of the superior portion passing uninterruptedly over it.

The **petrous ganglion** (**g. petrosum**) is larger than the jugular and involves the entire nerve. It is oval or fusiform in shape, measures from 4–5 mm. in length, and is lodged within a slight depression in the lower part of the groove for the nerve in the jugular foramen.

The **communications of the petrous ganglion** include filaments (*a*) from the superior cervical ganglion of the sympathetic, (*b*) to the auricular branch of the vagus and sometimes (*c*) to the ganglion of the root of the vagus.

Branches.—The branches of the glosso-pharyngeal nerve are: (1) the *tympanic*, (2) the *pharyngeal*, (3) the *muscular*, (4) the *tonsillar* and (5) the *lingual*.

1. The **tympanic nerve** (**n. tympanicus**) or *Jacobson's nerve*, arises from the petrous ganglion as its most important branch and traverses a tiny canal in the osseous bridge between the jugular fossa and the carotid canal. Entering the tympanic cavity and receiving fibres from the carotid plexus of the sympathetic by way of the **small deep petrosal** (**n. caroticotympanicus**), the tympanic nerve passes upward and forward in a groove on the promontory and breaks up in this situation to form the **tympanic plexus** (**plexus tympanicus [Jacobsoni]**). After distributing filaments to the mucous membrane lining the tympanic cavity and the associated air-spaces (mastoid cells and Eustachian tube), its fibres reassemble and join with a filament from the geniculate ganglion to continue as the small superficial petrosal nerve to the otic ganglion (Fig. 1075).

Branches.—These are: (*a*) the *small superficial petrosal nerve*, (*b*) the *branch to the fenestra ovalis*, (*c*) the *branch to the fenestra rotunda*, (*d*) the *branch to the Eustachian tube*, (*e*) the *branch to the mastoid cells* and (*f*) the *branch to the great superficial petrosal nerve.*

a. The *small superficial petrosal nerve* (**n. petrosus superficialis minor**) (Fig. 1075) is the continuation of the tympanic nerve, formed by a reassembling of the fibres of the plexus, supplemented by a filament from the geniculate ganglion of the facial. It traverses a canal which begins at the anterior superior portion of the tympanic cavity, passes beneath the upper end of the canal for the tensor tympani and appears on the superior surface of the petrous portion of the temporal bone, to the outer side of the cranial opening of the hiatus Fallopii. While in the canal it sometimes receives a communicating branch from the great superficial petrosal nerve. It leaves the cranium through a canal in the greater wing of the sphenoid, or through the fissure between the greater wing and the petrous portion of the temporal bone, and on reaching the base of the skull, joins the otic ganglion as its sensory root (Fig. 1075).

b. The *branch to the fenestra ovalis* supplies the mucous membrane in the neighborhood of the oval window.

c. The *branch to the fenestra rotunda* is distributed to the mucous membrane over and around the fenestra.

d. The *branch to the Eustachian tube* supplies the mucous membrane lining the osseous portion of that canal.

e. The *branch to the mastoid cells* supplies the mucous lining of these cells.

f. The *branch to the great superficial petrosal nerve* joins the latter in the hiatus Fallopii.

2. The **pharyngeal branches** (**rr. pharyngei**) number two or more, of which the largest descends along the course of the internal carotid artery and joins the pharyngeal branches of the vagus and sympathetic to form the **pharyngeal plexus,** which supplies the mucous membrane and muscles of the pharynx. The smaller pharyngeal branches pierce the superior constrictor and are distributed to the mucous membrane lining the upper portion of the pharynx.

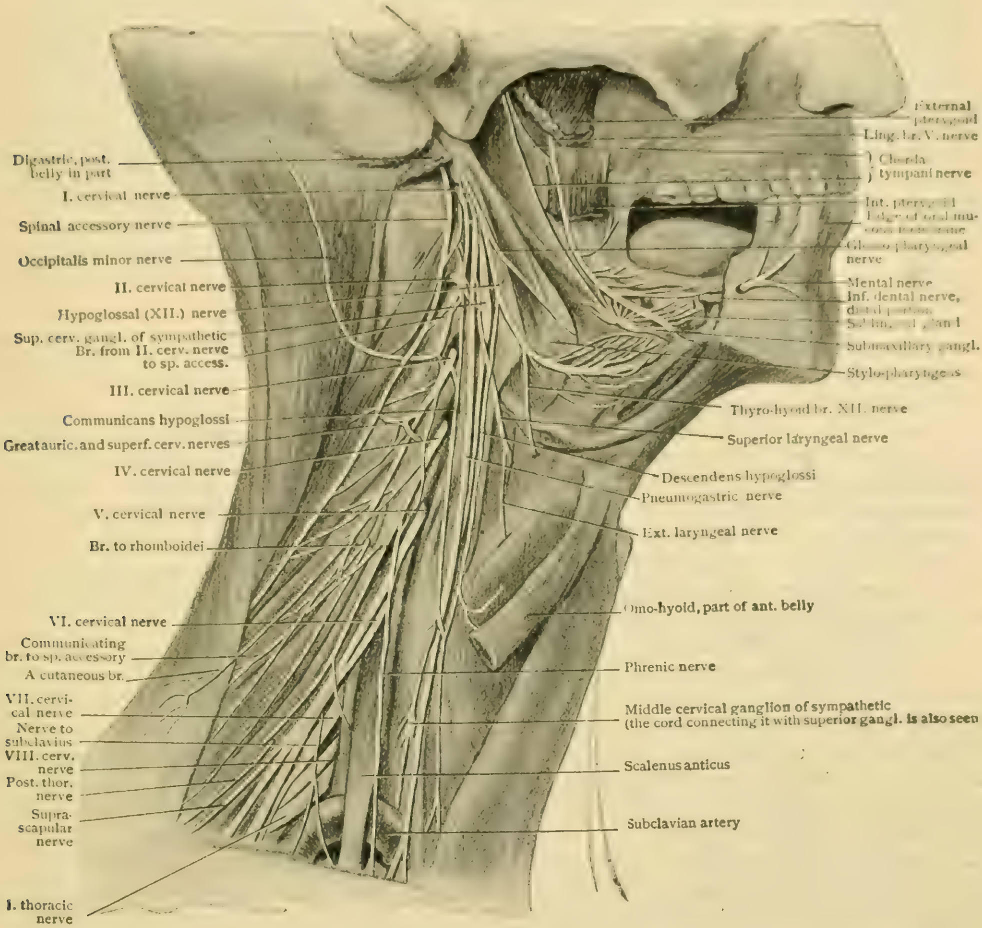
3. The **muscular branch** (**r. stylopharyngeus**) enters the stylo-pharynegus, and, after giving off fibres for the supply of that muscle, passes through it to be distributed to the mucous membrane of the pharynx.

4. The **tonsillar branches** (**rr. tonsillares**) are given off near the base of the tongue. They are slender filaments which form a plexiform ramification, the *circulus tonsillaris*, around the tonsil. From this plexus filaments are distributed to the tonsil, the soft palate and the faucial pillars.

5. The **lingual branches** (**rr. linguales**) are the two terminal filaments of the nerve. The larger *posterior branch* passes upward and separates into a number of filaments which supply the circumvallate papillæ and the mucous membrane covering

the posterior part of the dorsum of the tongue, the glosso-epiglottic and pharyngo-epiglottic folds and the lingual surface of the epiglottis. The smaller *anterior branch* supplies the mucous membrane of the side of the tongue half way to the tip.

FIG. 1076.



Deep dissection of neck showing ninth, tenth, eleventh and twelfth cranial nerves and their branches.

Variation.—Instances are recorded in which the mylo-hyoid nerve was absent and a branch of the glosso-pharyngeal supplied the mylo-hyoid muscle and the anterior belly of the digastric, the innervating fibres being, probably, aberrant filaments of the trigeminus.

THE VAGUS NERVE.

The tenth, vagus or pneumogastric nerve (**n. vagus**) is the longest and most widely distributed of the cranial series. Starting in the cranium, it passes through the neck, thorax and upper part of the abdomen before breaking up into its terminal branches. In addition to certain filaments concerned with special functions, distributed to the heart and abdominal viscera, it contains both motor and sensory fibres. Some of the motor constituents of the nerve arise from its own origin, but the majority perhaps are contributions of the *accessorius vagi*, the so-called accessory part of the spinal accessory nerve. The vagus supplies motor fibres to the muscles of the soft palate (with the exception of the tensor palati and, probably, partly the levator palati and azygos uvulæ), pharynx, œsophagus, stomach, and intestine (with the exception of the rectum), and to those of the larynx, trachea, and bronchi and their subdivisions. It distributes sensory fibres to the dura mater, external ear, pharynx, œsophagus, stomach, larynx, trachea, bronchi and subdivisions and pericardium.

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Special fibres are furnished to the heart, liver, spleen, pancreas, kidneys, suprarenal bodies and intestinal blood-vessels.

It is generally admitted that the bulbar or accessory portion of the eleventh nerve forms an integral part of the motor division of the vagus, and, hence, should be included with the efferent fibres of the tenth. As to the ultimate distribution of these accessory fibres, and conversely of the vagus motor fibres proper, much discussion and many conflicting views have existed and, even at present, a consensus of opinion can scarcely be said to have been reached. After reviewing the evidence, both anatomical and experimental, Van Gehuchten[1] concludes that the accessory fibres are distributed chiefly, if not indeed exclusively, to the larynx through the inferior laryngeal branch of the vagus, and are continued neither to the heart nor to the stomach. The efferent vagus fibres proceeding to the heart are inhibitory in function ; whether they directly reach the cardiac muscle is doubtful, since, reasoning from analogy, it is probable that the vagus fibres end around sympathetic neurones whose axones are the filaments coming into immediate relations with the muscle-fibres. Of the efferent fibres of the vagus distributed to the stomach and other parts of the digestive tract, some are secretory, while others, possibly, influence the caliber of the blood-vessels, in both cases being interrupted in sympathetic ganglia before gaining their destination.

Deep Origin of the Motor Portion.—As stated above, the efferent fibres of the vagus consist of two sets, vagus fibres proper and those derived from the accessory portion of the spinal accessory. The former have their deep origin in the *nucleus ambiguus* and the *dorsal motor nucleus*, in series with the motor fibres of the ninth nerve ; the accessory fibres arise from the nucleus ambiguus only. The detailed description of these nuclei has been given (page 1260). The fibres arising from the nucleus ambiguus at first pass backward toward the floor of the fourth ventricle, then bend sharply outward and, condensed into compact strands that receive the fibres originating from the motor cells of the dorsal nucleus, proceed, ventro-laterally in company with the sensory fibres, to their *superficial origin* along the postero-lateral groove behind the olivary eminence.

Central Connections of the Sensory Portion.—The afferent root-fibres of the vagus are the axones of the neurones lying within the ganglia of the root and of the trunk situated on the upper part of the nerve. The centrally directed processes pass into the medulla, in company with the motor strands, and divide into two sets. Those forming the larger of these end in arborizations around the cells within the lower portion of the *dorsal sensory nucleus ;* those of the smaller set bend downward and enter the *fasciculus solitarius* to terminate in arborizations around the cells of the spinal nucleus of reception. (For details of these nuclei see page 1260). As in the case of the other mixed nerves—the fifth, seventh and ninth—the secondary paths distributing the sensory impulses include (*a*) fibres that pass from the reception-nuclei to the tract of the mesial fillet, and so on to the great brain, and (*b*) those that pass to the cerebellum.

Course and Distribution.—The vagus, disregarding its accessory fibres which at first are incorporated in a common trunk with the eleventh nerve, arises from its **superficial origin** by a row of twelve or fifteen filaments which emerge from the surface of the medulla along the postero-lateral sulcus between the olivary eminence and the inferior cerebellar peduncle. These fasciculi lie in series with those of the ninth nerve above and of the eleventh below (Fig. 1046).

After leaving the surface of the brain-stem, the converging rootlets of the vagus fuse to form a single flattened trunk, which passes outward beneath the flocculus of the cerebellum to the jugular foramen (Fig. 1074). The trunk leaves the cranium through the rear division of the middle compartment of this foramen, invested by a dural sheath shared by the spinal accessory nerve. In this situation it presents a ganglionic enlargement called the *ganglion of the root.* Emerging from the jugular foramen, the vagus bears a second thickening, the *ganglion of the trunk*, and enters the carotid sheath, through which it passes downward the entire length of the neck. Within the carotid sheath the nerve lies at first between the internal carotid artery and the internal jugular vein, and then between the common carotid artery and the vein, occupying the posterior groove between these vessels. At the root of the

[1] Anatomie du Système Nerveux, 1906.

neck it leaves the carotid sheath and becomes an occupant of the thorax. Entering the thoracic cavity the nerve traverses first the superior and then the posterior mediastinum, its course differing widely on the two sides.

The **right vagus** (Fig. 1090), after passing in front of the first portion of the subclavian artery and behind the right innominate vein and the superior vena cava, descends along the right side of the trachea to reach the posterior aspect of the root of the lung. Here the entire nerve breaks up to form the *posterior pulmonary plexus*, which assembles at its lower border to form two cords. These pass inward across the vena azygos to the œsophagus and again break up to unite with a similar contribution from the left side to form the *œsophageal plexus* (Fig. 1081). On approaching the œsophageal opening in the diaphragm, the fibres of the plexus become reunited to form the continuation of the trunks of the two vagus nerves. The right vagus, somewhat larger than the left, follows the posterior aspect of the œsophagus and, after entering the abdomen through the œsophageal opening, is

Fig. 1077.

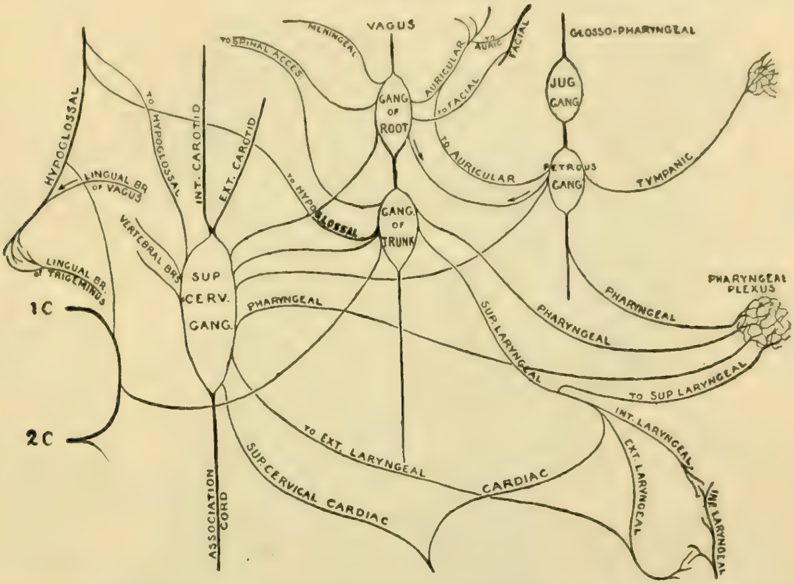


Diagram showing connections between the superior cervical sympathetic ganglion and the glosso-pharyngeal, vagus and hypoglossal nerves.

distributed to the posterior surface of the stomach and to the solar plexus, and indirectly to the spleen, pancreas, intestine, kidney and suprarenal body.

The **left vagus**, after passing between the left common carotid and subclavian arteries and behind the left innominate vein, crosses the anterior surface of the aorta and then bends backward to reach the posterior surface of the root of the lung. In a manner similar to the right, it forms the *posterior pulmonary plexus* and reassembles into two cords. These pass inward anteriorly to the thoracic aorta and enter the *œsophageal plexus*, at the lower end of which the fibres of the left nerve gather on the anterior surface of the œsophagus, traverse as a single solid trunk the œsophageal opening and are distributed to the anterior surface of the stomach and to the liver.

Ganglia of the Vagus Nerve.—Two ganglia are found in the course of the nerve, the *ganglion of the root* and the *ganglion of the trunk*. They are collections of neurones whose axones form the sensory root-fibres of the vagus, the greater number, however, being connected with the cells of the ganglion of the root.

The **ganglion of the root** (g. jugulare) or **upper ganglion** (Fig. 1077) is a grayish spherical mass of nerve-cells, about 4 mm. in length, situated in the upper part of the jugular foramen.

The **communications** of this ganglion include filaments which pass between the ganglion and (*a*) the facial and (*b*) spinal accessory nerves, (*c*) the superior cervical ganglion of the sympathetic nerve and (*d*) the petrous ganglion of the glosso-pharyngeal.

The **ganglion of the trunk** (g. nodosum) or **lower ganglion** (Fig. 1077) is a reddish, flattened, fusiform group of nerve-cells. It lies beneath the jugular foramen, about 1 cm. below the ganglion of the root, and measures from 1.5–2 cm. in length and about 4 mm. in diameter. The accessory part of the spinal accessory nerve passes over the ganglion on its way to fuse with the vagus, which it does usually immediately beyond the ganglion.

The **communications** of this ganglion include filaments which pass between the ganglion and (*a*) the hypoglossal and (*b*) spinal accessory nerves, (*c*) the loop between the first and second cervical nerves and (*d*) the superior cervical ganglion of the sympathetic.

Branches.—The vagus nerve gives off the following branches: from the ganglion of the root, (1) the *meningeal* and (2) the *auricular;* from the ganglion

FIG. 1078.

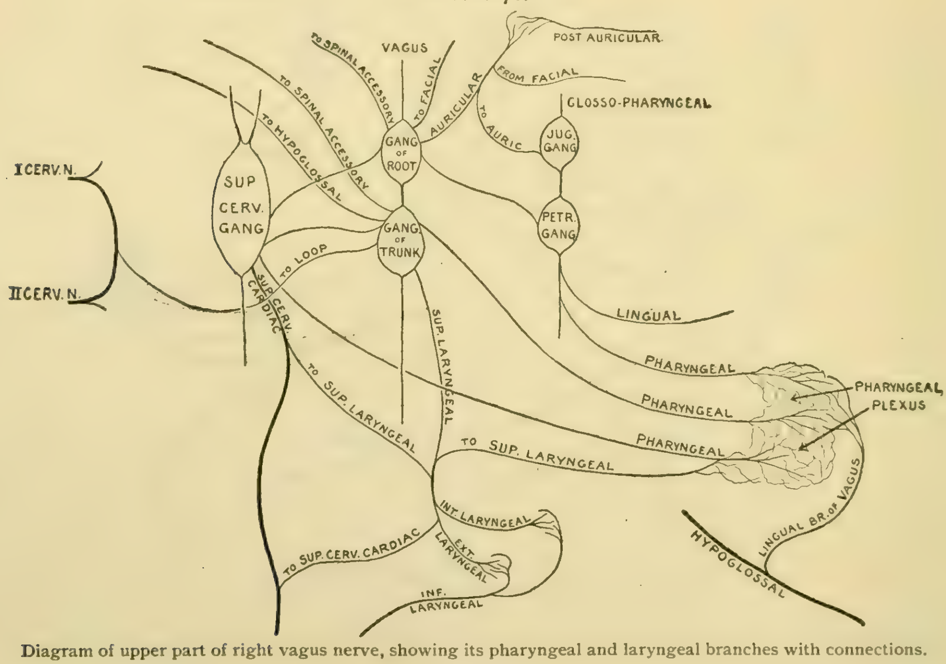


Diagram of upper part of right vagus nerve, showing its pharyngeal and laryngeal branches with connections.

of the trunk, (3) the *pharyngeal* and (4) the *superior laryngeal;* in the neck, (5) the *superior cervical cardiac*, and (6) the *inferior cervical cardiac;* in the thorax, (7) the *inferior laryngeal*, (8) the *thoracic cardiac*, (9) the *anterior pulmonary*, (10) the *posterior pulmonary*, (11) the *œsophageal* and (12) the *pericardial;* and in the abdomen, (13) the *abdominal.*

1. The **meningeal branch** (r. meningeus) arises from the ganglion of the root and follows a recurrent course upward through the jugular foramen to supply the dura mater of the posterior fossa of the cranium, especially in the vicinity of the lateral and occipital sinuses.

2. The **auricular branch** (r. auricularis) is given off from the ganglion of the root. It receives a filament of communication from the petrous ganglion of the ninth nerve and follows the outer margin of the jugular foramen to an opening between the stylo-mastoid and jugular foramina. Entering this foramen it traverses a canal in the temporal bone which crosses the inner side of the facial canal and terminates between the mastoid process and the external auditory meatus.

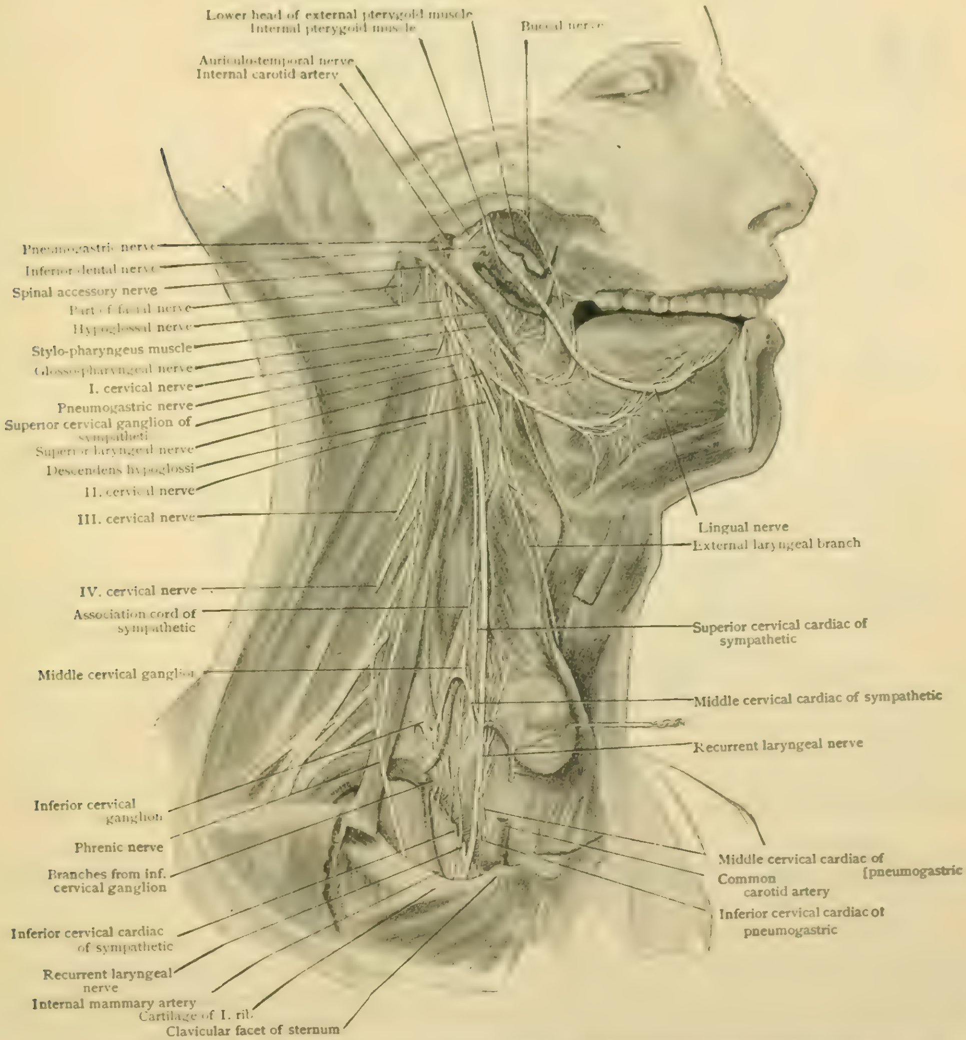
Leaving the canal the nerve supplies the skin of the posterior part of the auricle and of the posterior inferior portion of the external auditory meatus.

While traversing the temporal bone the auricular nerve communicates with the facial and, after reaching its area of distribution, with the posterior auricular nerve.

Variations.—The auricular nerve may be absent or may fuse with the main trunk of the facial, its fibres under these circumstances probably reaching their destination through the posterior auricular nerve. Its branch of communication with the facial may be absent.

3. The **pharyngeal branches** (rr. pharyngei), usually an upper and a lower but sometimes more or only one, are given off from the upper portion of the gang-

Fig. 1079.



Deep dissection of right side of head and neck, showing lingual, glosso-pharyngeal, pneumogastic, hypoglossal and sympathetic nerves.

lion of the trunk and include to a considerable extent fibres brought to the vagus by its accessory portion. They pass downward and inward, between the external and internal carotid arteries, and join the pharyngeal branches from the glosso-pharyngeal nerve and from the superior cervical ganglion of the sympathetic to form the *pharyngeal plexus* (**plexus pharyngeus**) (Fig. 1078). This plexus contains one or

more minute sympathetic ganglia and ramifies over the middle constrictor of the pharynx. It supplies motor fibres to the muscles of the pharynx and of the soft palate, with the exception of the stylo-pharyngeus and the tensor palati. From the plexus proceed sensory filaments to the mucous membrane of the pharynx. A filament from this plexus, the *lingual branch of the vagus* (**r. lingualis vagi**), composed of fibres from both the ninth and tenth nerves, joins the hypoglossal as it hooks around the occipital artery.

Variation.—A slender branch, the *middle laryngeal nerve*, is described as arising from the pharyngeal plexus and supplying the crico-thyroid muscle, after which it pierces the crico-thyroid membrane and supplies the mucous membrane of the lower part of the larynx.

4. The **superior laryngeal nerve** (**n. laryngeus superior**) (Fig. 1079) arises from the middle of the ganglion of the trunk and takes a downward and inward course beneath the external and internal carotid arteries toward the superior cornu of the thyroid cartilage. It divides terminally into (*a*) the *external* and (*b*) *internal laryngeal* branches.

Communications.—Before dividing, the *superior laryngeal nerve* receives filaments from the superior cervical sympathetic cardiac and from the pharyngeal plexus.

The cardiac twig given off by the *external laryngeal nerve* joins with the superior cervical cardiac branch of the sympathetic. In the lower part of the larynx the external laryngeal nerve inosculates with the terminal fibres of the internal laryngeal.

At the inferior portion of the larynx, the *internal laryngeal nerve* communicates with the terminal filaments of the external laryngeal, and in this way supplies sensory fibres to the mucous membrane lining the lower part of the larynx and to the muscles.

Variation.—Instead of passing to the inner side of the internal carotid artery the nerve may lie external to it.

a. The **external laryngeal branch** (**r. externus**), much smaller than the internal, passes downward upon the inferior constrictor of the pharynx and beneath the infrahyoid muscles to the crico-thyroid muscle, which it supplies. It sends filaments also to the inferior pharyngeal constrictor and gives off a cardiac twig which joins the superior cervical cardiac branch of the sympathetic.

Variations.—The external laryngeal has been seen to send filaments to the thyroid gland, the pharyngeal plexus, the sterno-hyoid, sterno-thyroid, thyro-hyoid and crico-arytenoideus lateralis muscles and to the mucous membrane of the vocal cord and lower portion of the larynx.

b. The **internal laryngeal branch** (**r. internus**), larger than the external, passes downward and inward between the middle and inferior constrictors of the pharynx and enters the larynx by piercing the thyro-hyoid membrane. By means of its *epiglottic*, *pharyngeal*, *descending* and *communicating* branches, it supplies the mucous membrane covering the internal and pharyngeal surfaces of the larynx and the mucous membrane of the base of the tongue.

Variation.—Instead of piercing the thyro-hyoid membrane the nerve may obtain entrance to the larynx through a small foramen in the thyroid cartilage.

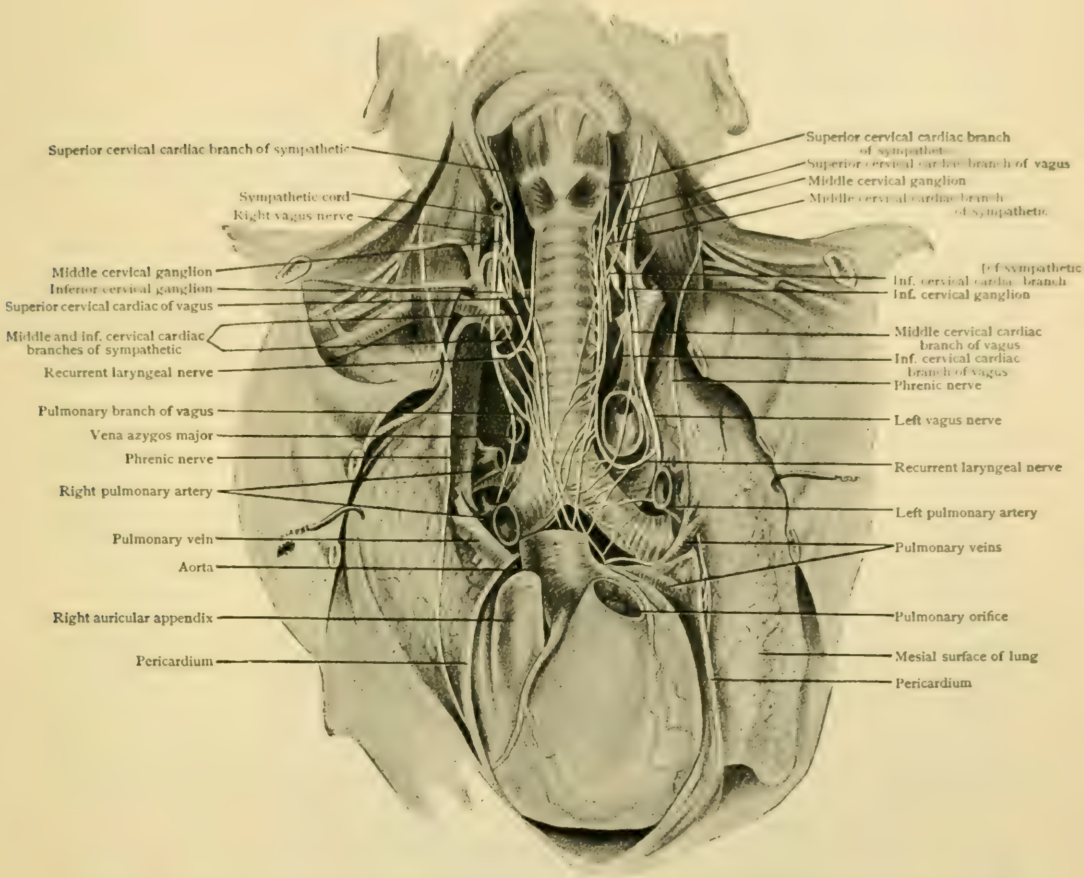
5. The **superior cervical cardiac branch** (**rr. cardiaci superiores**—both cervical cardiacs) arises from the vagus in the upper part of the neck. It either joins a cardiac branch of the vagus or passes independently down the neck and along the side of the trachea to end in the deep cardiac plexus (Fig. 1132).

6. The **inferior cervical cardiac branch** leaves the vagus at the root of the neck. On the right side it courses along the side of the innominate artery and either independently, or after joining one of the other cardiac nerves, enters the deep cardiac plexus. The left passes in front of the arch of the aorta and joins the superior cervical cardiac branch of the left sympathetic to form the superficial cardiac plexus (Fig. 1132).

7. The **inferior or recurrent laryngeal nerve** (**n. recurrens**) (Fig. 1080) differs on the two sides in the early part of its course. The *right nerve* is given off at

the root of the neck as the vagus crosses the anterior surface of the subclavian artery, from which point it passes under and behind the artery and ascends. The *left nerve* takes its origin as the vagus crosses the anterior aspect of the aortic arch, and after passing below and behind the arch, lateral to the obliterated ductus arteriosus, ascends in the superior mediastinum to enter the neck. After entering the neck the further course of the nerve is the same on both sides. It passes upward posterior to the carotid sheath, either anterior or posterior to the inferior thyroid artery, occupies the

Fig. 1080.



Dissection showing cardiac branches of pneumogastric nerves and of sympathetic cords; aortic arch and branches and pulmonary artery partially removed; pericardium laid open.

groove between the œsophagus and the trachea, and, dipping beneath the lower edge of the inferior constrictor of the pharynx, enters the larynx at the inferior margin of the cricoid cartilage.

The asymmetry observed in the first part of the course of the nerves of the two sides is secondary and referable to the changes incident to the development of the large arterial trunks. In the fœtus both nerves hook around the fourth aortic arch of the corresponding sides and are, therefore, for a time symmetrically disposed. Since, however, on the left side this arch becomes the arch of the aorta, and on the right the innominate and subclavian arteries (page 726), it is evident that the vagi, although retaining their primary associations, later alter their actual position and relations in consequence of the unequal growth and downward displacement which these blood-vessels undergo.

Branches.—During its course the inferior laryngeal nerve gives off: (*a*) the *cardiac*, (*b*) the *tracheal*, (*c*) the *œsophageal*, (*d*) the *muscular* and (*e*) the *terminal* branches.

a. The **cardiac branches** (rr. cardiaci inferiores) are given off in the superior mediastinum and enter the deep cardiac plexus.

b and *c.* **Tracheal** and **œsophageal branches** (rr. tracheales et oesophagei) are given off as the nerve ascends in the neck between the trachea and œsophagus.

d. **Muscular branches** enter the inferior constrictor of the pharynx.

e. The **terminal branches** (n. laryngeus inferior) are formed at the point where the nerve breaks up on the inner side of the thyroid cartilage. They supply the intrinsic muscles of the larynx, with the exception of the crico-thyroid.

As it turns to ascend, the inferior laryngeal nerve **communicates** with the inferior cervical ganglion of the sympathetic, its terminal filaments joining with those of the internal laryngeal.

Variations.—The inferior laryngeal nerve has been seen to supply twigs to the crico-thyroid muscle. In cases in which the subclavian artery arises dorsally, the right recurrent laryngeal passes directly downward and inward from the vagus to the larynx.

8. The **thoracic cardiac nerves** (rr. cardiaci inferiores) of the right side are derived both from the vagus as it lies beside the trachea and from the inferior laryngeal. Those of the left side arise exclusively from the inferior laryngeal. They help to form the deep cardiac plexus.

9. The **anterior pulmonary branches** (rr. bronchiales anteriores) are two or three small filaments which, on the right side, receive communicating fibres from the deep cardiac plexus and, on the left side, are joined by filaments from both cardiac plexuses. These unite to form the **anterior pulmonary plexuses** (plexus pulmonales anteriores) (Fig. 1080), which communicate with each other and with the posterior plexuses, and ramify over and supply the anterior aspect of the bronchus and root of the lung.

10. The **posterior pulmonary branches** (rr. bronchiales posteriores) are several large twigs which join with filaments from the second, third and fourth thoracic ganglia of the sympathetic to form the **posterior pulmonary plexus** (plexus pulmonalis posterior). Fibres from this plexus communicate with the corresponding structure of the opposite side and with the anterior pulmonary plexuses, in this way each vagus sending fibres to both lungs. Branches from the plexus, bearing tiny ganglia, follow the subdivisions of the bronchi to supply the ultimate units of the lung.

11. The **œsophageal branches** (rr. oesophagei) are given off in two situations: in the superior mediastinum, where the right vagus and the left inferior laryngeal distribute œsophageal branches, and in the posterior mediastinum, where the œsophagus is surrounded by branches from the **œsophageal plexus** or *plexus gulæ* (Fig. 1081). This plexus is composed of the two vagus nerves, after they leave the posterior aspect of the bronchi, in conjunction with filaments from the great splanchnic nerves and from some of the lower thoracic ganglia. Both the muscular and mucous coats of the œsophagus are innervated from this source.

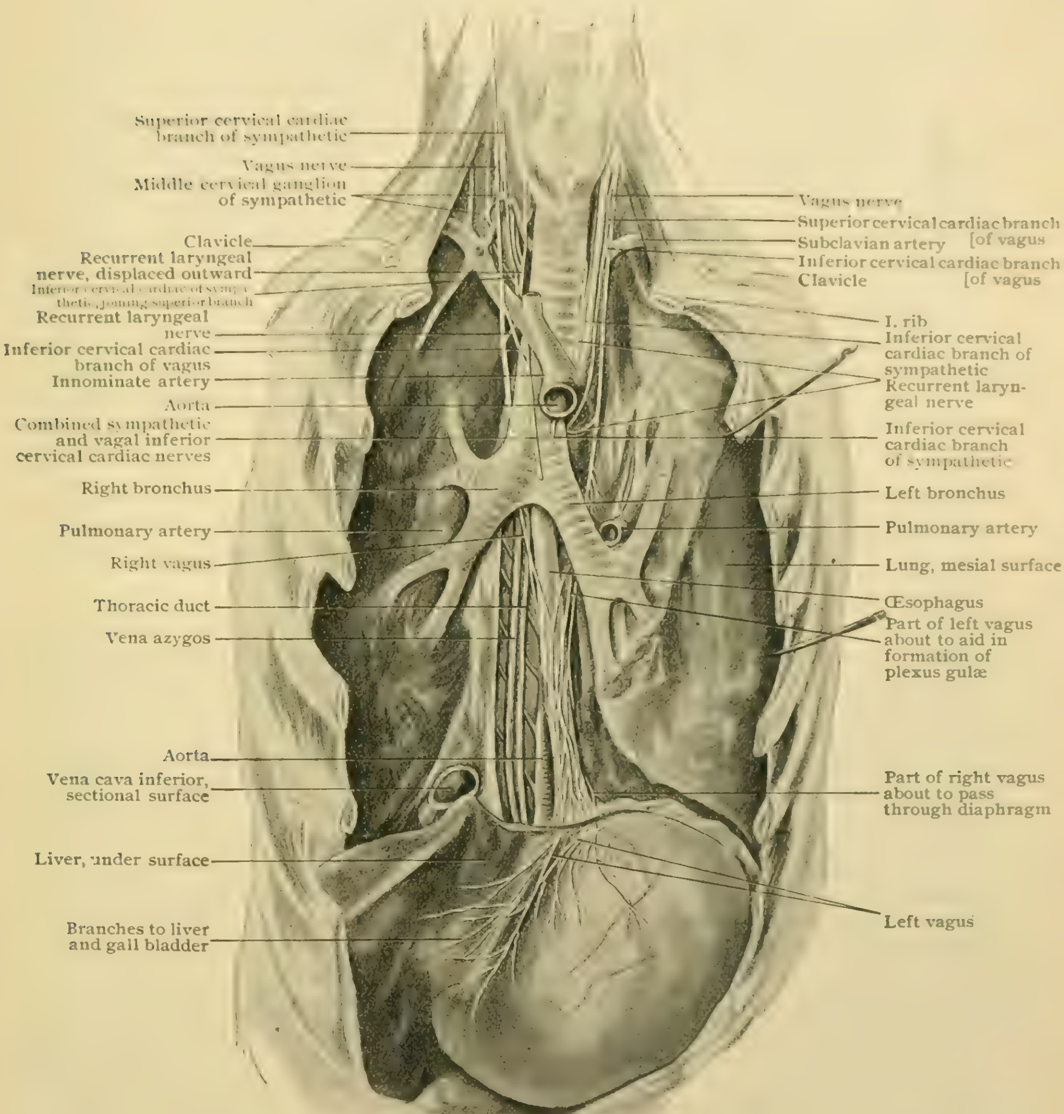
12. The **pericardial branches** (rr. pericardiaci) are given off to the upper anterior portion of that membrane by either vagus and to the posterior portion by the œsophageal and frequently the posterior pulmonary plexuses.

13. The **abdominal branches** come from both nerves. On gaining the posterior surface of the stomach after following the corresponding aspect of the œsophagus, the **right vagus** forms the *posterior gastric plexus* along the lesser curvature, from which *gastric branches* supply the posterior surface of the stomach; the remaining and larger part of the plexus is continued as the *cœliac branches* to the plexus of the same name and, thence, in company with the sympathetic strands, to the subsidiary plexuses supplying the spleen, the pancreas, the intestine, the suprarenal bodies and the kidneys. In a similar manner, along the lesser curvature the **left vagus** forms the *anterior gastric plexus*, from which numerous *gastric branches* are distributed to the anterior surface of the stomach, the continuation of the plexus being *hepatic branches*, which join the sympathetic filaments accompanying the hepatic artery to supply the liver.

Practical Considerations.—The pneumogastric nerve may be compressed or displaced by tumors in the neck, or it may be injured in accidental or operative wounds, or by fracture of the base of the skull. Its division is not always fatal; in

fact, a portion of it has been deliberately removed with success. In those cases in which the nerve was divided, difficulty in breathing and swallowing, slowing of the respiration, laryngismus, changes in the voice, diminished inspiratory murmur, asthma and pneumonia were noticed (Park). In cases of pressure by tumors on the pneumogastrics of both sides, lung disturbances, dyspnœa, weakening of the pulse, and a ravenous appetite were observed.

FIG. 1081.



Dissection showing lower part of pneumogastric nerves and their branches.

Lesions of the *recurrent laryngeal branch* of the pneumogastric, from tumors, abscesses, etc., are comparatively common. Injury to this nerve is the chief danger to be feared in the removal of the thyroid gland, passing as it does so close to the gland and to the inferior thyroid artery where the latter is usually ligated preliminary to or during the excision of the gland. As it is the main motor nerve of the larynx,

its irritation causes spasm of the laryngeal muscles, with brassy cough and stridulous breathing. The tendency to closure of the glottis is sometimes so threatening as to demand immediate tracheotomy or intubation. Paralysis causes hoarseness or loss of voice (aphonia). In a bilateral paralysis both cords fall into the cadaveric position. Loss of voice results and marked inspiratory dyspnœa, which may demand tracheotomy or intubation.

THE SPINAL ACCESSORY NERVE.

The eleventh or spinal accessory nerve (**n. accessorius**) is purely motor. It consists of two portions, a *spinal* and an *accessory*, which differ widely in origin, course and distribution. The spinal portion or *accessorius spinalis* (**r. externus**) is so termed because it arises from the spinal cord and the accessory portion or *accessorius vagi* (**r. internus**) receives its name in recognition of the fact that it is accessory to the vagus. As emphasized in connection with the last-named nerve (page 1266), the so-called accessory portion of the eleventh is, in reality, an integral part of the vagus and the description of its deep origin and distribution has been included with those of the vagus. There remains, therefore, only the spinal portion of the nerve to be considered. The spinal part—the eleventh nerve proper—supplies the sterno-mastoid and trapezius muscles.

Deep Origin.—The fibres constituting the spinal part of the nerve arise as the axones of a column of large multipolar neurones which is situated in the anterior horn of the spinal gray matter and extends from the lower end of the medulla to the fifth or sixth cervical segment of the spinal cord. The cells of this column, known as the *accessory nucleus*, occupy a dorso-lateral position in the horn, lying posterior to the cells from which arise the fibres of the anterior roots of the cervical nerves. Leaving these cells, the fibres pass dorsally within the gray matter to the vicinity of the bay between the anterior and posterior horns, where, while some at once curve outward and traverse the white matter to gain the lateral surface of the cord, the majority bend abruptly brainward and pursue a short ascending path before turning outward.

Course and Distribution.—The **superficial origin** of the accessory nerve is marked by the emergence of a series of fasciculi along the lateral surface of the spinal cord between the anterior and posterior roots of the cervical spinal nerves, the fasciculi progressively nearing the posterior roots as they issue at higher levels. Consecutively joining shortly after they escape from the cord, the fasciculi unite to form a common trunk, which gradually increases in size by accessions of fibres at each succeeding segment. The nerve-trunk thus formed passes upward in the subdural space, between the ligamentum denticulatum and the posterior nerve-roots (Fig. 879), to the foramen magnum, through which it enters the cranium. Upon reaching the side of the medulla, the spinal accessory nerve turns outward to enter the middle compartment of the jugular foramen and to unite temporarily with the accessory vagus. It occupies the posterior part of the middle compartment of the jugular foramen, lying within a dural sheath which contains also the vagus. On reaching the lower margin of the foramen, the fibres accessory to the vagus permanently leave the eleventh nerve. The latter, often described as the spinal part, courses downward for a short distance in the interval between the internal carotid artery and the internal jugular vein and then passes backward, either anterior or posterior to the vein, until it reaches the deep surface of the sterno-mastoid muscle, which it usually enters. While within the substance of the muscle, the spinal accessory gives off filaments which unite with a branch from the second cervical nerve to form the *sterno-mastoid plexus* (Fig. 1082) for the supply of that muscle. Emerging from beneath the posterior edge of the sterno-mastoid, the eleventh nerve crosses the occipital triangle and dips under the anterior margin of the trapezius along the deep surface of which it descends almost to the lower margin of the muscle. Under the trapezius the nerve forms a plexus of varying degrees of intricacy with the third and fourth cervical nerves. This is called the *subtrapezial plexus* (Fig. 1082), its fibres of distribution supplying solely the trapezius muscle.

Variations.—Considerable deviation from the normal has been described with regard to the spinal portion. The lower limit of its origin has been observed as high as the third cervical nerve and from that level as far down as the first thoracic. In one instance the nerve left the subdural space below the first cervical nerve and re-entered at a higher level. Quite frequently it fails to pierce the sterno-mastoid muscle. In one reported case the nerve ended in the sterno-mastoid, the trapezius being supplied only by the third and fourth cervical nerves. Two similar cases have been observed in the dissecting room of the University of Pennsylvania. Rarely it gives off a filament which joins the n. descendens cervicalis.

Practical Considerations.—The spinal accessory nerve supplies the sterno-cleido-mastoid and trapezius muscles. A few fibres of the second and third cervical nerves enter into the supply of the sterno-mastoid, but the muscle is almost completely under the control of the spinal accessory. The cervical nerves take a greater part in the supply of the trapezius, so that paralysis of the spinal accessory does not always paralyze this muscle.

Spasm of the trapezius will draw the head backward and toward the affected side and will pull the scapula toward the spine. In spasm of the sterno-mastoid, as in "wry neck," the chin will be turned to the opposite side and elevated, while the ear will look forward. If both sterno-mastoids are in contraction the chin will be in the median line and will be drawn toward the sternum. Paralysis of one muscle will produce a condition somewhat similar to that produced by a spasm of the opposite one.

The spinal accessory nerve enters the under surface of the sterno-mastoid muscle near the junction of its upper and middle thirds, where it may be reached by an incision along the anterior border of the muscle. The nerve emerges from the muscle near the middle of its posterior border.

THE HYPOGLOSSAL NERVE.

The twelfth or hypoglossal nerve (**n. hypoglossus**) is a purely motor nerve and supplies the musculature of the tongue, intrinsic as well as extrinsic, with the exception of the palato-glossus.

Central and Cortical Connections.—The hypoglossal nerve takes its **deep origin** from several associated groups of neurones called the **hypoglossal nucleus** (**nucleus n. hypoglossi**) (Fig. 949), which underlies the floor of the fourth ventricle. This nucleus is a narrow elongated collection of large multipolar cells, measuring about 18 mm. in length by 2 mm. in width, that partly corresponds in position to the *trigonum hypoglossi* in the floor of the fourth ventricle. The entire nucleus, however, is more extensive than the trigonum and extends from the level of the striæ acusticæ above into the closed part of the medulla as far down as the decussation of the pyramids (Fig. 927). It lies ventral and very slightly lateral to the central canal of the medulla and the median groove in the floor of the fourth ventricle, close to the mid-line and its fellow of the opposite side. The large size and branched form of the nerve-cells composing the nucleus, as well as their ventral position in relation to the central canal, emphasize the close correspondence of these elements with the cells of the motor roots of the spinal nerves. Indeed, as noted later (page 1380), the gray matter enclosing the hypoglossal nucleus is the morphological equivalent of the bases of the anterior cornua. Immediately after arising and before leaving the nucleus, the axones converge into a number of fasciculi which, emerging from the ventral aspect of the nucleus, take a ventro-lateral course and traverse the interval between the gray and white reticular formations. From this situation the hypoglossal fibres continue their course to the anterior surface of the medulla by passing, for the most part, between the nucleus of the inferior olive and the mesial accessory olivary nucleus, although quite a number of the strands penetrate the ventral portion of the olivary nucleus (Fig. 927).

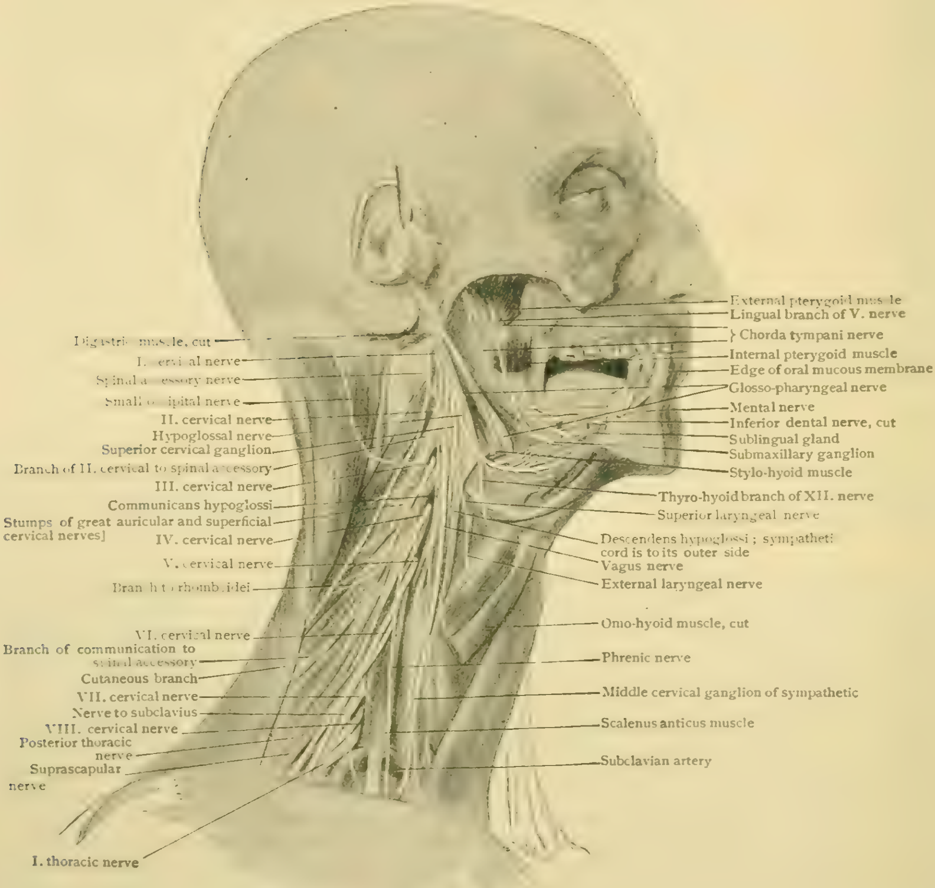
The **central connections** of the hypoglossal nucleus include: (*a*) crossed fibres from the nucleus of the opposite side; (*b*) fibres from, and probably also to, the posterior longitudinal fasciculus, by means of which the nucleus of the twelfth is brought into relation with the nuclei of other motor nerves; and (*c*) fibres which join the dorsal bundle of Schütz, a system of longitudinal fibres underlying the floor of the fourth ventricle and traceable upward beneath the Sylvian aqueduct, by which the nuclei of the sensory cranial nerves are connected.

The **cortical centre** of the hypoglossal nerve probably lies within the lower or opercular extremity of the precentral convolution. The fibres arising as the axones of the cells within this area pass over the upper border of the lenticular nucleus and through the internal capsule and descend in the brain-stem within the median part of the pyramidal tract as far as the

medulla. The cortico-nuclear fibres then bend dorso-medially and, for the most part but not entirely, cross the raphe to enter the ventro-lateral surface of the hypoglossal nucleus of the opposite side and end in arborizations around the root-cells.

Course and Distribution.—The hypoglossal takes its **superficial origin** from the surface of the brain-stem in the form of from ten to fifteen slender fasciculi, which emerge from the ventral surface of the medulla in the groove between the olivary eminence and the pyramid (Fig. 1046).

FIG. 1082.



Deep dissection of neck showing branches of vagus, spinal accessory and hypoglossal nerves.

These root-bundles pass outward, dorsal to the vertebral artery, and assemble into two groups, which pierce the dura mater separately at a point opposite the anterior condyloid foramen. Either within this canal or as they leave the cranium through its external opening they unite into a single trunk. Arriving at the inferior aspect of the base of the skull, the deeply placed hypoglossal nerve descends and hooks around the ganglion of the trunk of the vagus, to which it is closely attached by connective tissue. It then takes a downward and forward course between the internal carotid artery and the internal jugular vein. Arriving at the inferior margin of the posterior belly of the digastric, the nerve winds around the occipital artery and courses downward and forward to the outer side of the external and internal carotid arteries. It then continues forward above the hyoid bone to the under surface of the tongue, passing beneath the tendon of the digastric,

under the stylo-hyoid and mylo-hyoid muscles and over the hyo-glossus (Fig. 1082). It terminates by piercing the genio-hyo-glossus and breaking up into a number of fibres for the supply of the lingual muscles.

Communications.—Immediately after emerging from the anterior condyloid foramen, (*a*) a tiny branch connects with the superior cervical ganglion of the sympathetic, (*b*) one or two filaments pass to the loop between the first and second cervical nerves and (*c*) several fibres associate the nerve with the ganglion of the trunk of the vagus. At the point where the hypoglossal nerve and the occipital artery cross, (*d*) the lingual branch of the vagus joins the twelfth; and as the nerve lies beneath the mylo-hyoid and upon the hyo-glossus muscle, it communicates with (*e*) the lingual branch of the mandibular nerve.

Branches.—The branches of the hypoglossal nerve are: (1) the *meningeal*, (2) the *descending*, (3) the *thyro-hyoid* and (4) the *lingual*.

1. The **meningeal branch** (r. meningeus) consists of one or two minute filaments which supply the dura mater of the posterior cranial fossa and the diploë of the occipital bone. As the hypoglossal is motor in function, it is likely that these twigs are contributed to the nerve by the loop between the first and second cervical nerves.

2. The **descending branch** (r. descendens), or *r. descendens hypoglossi*, is in reality only to a limited extent a branch of the twelfth, since the greater number of its fibres are accessions to the hypoglossal from the first and second cervical nerves. There is reason, however, to believe that these cervical nerves are not the exclusive source of the fibres of the descendens hypoglossi, but that some arise from the cells of the hypoglossal nucleus. The descending branch arises near the point where the hypoglossal nerve hooks around the occipital artery and runs downward and inward in front of or within the carotid sheath. It gives off a branch to the anterior belly of the omo-hyoid and, about the middle of the neck, joins the **descending cervical nerve**, or *n. communicans hypoglossi*, from the second and third cervical nerves. A loop or plexus, termed the *ansa hypoglossi*, is thus formed and from it filaments are supplied to the sterno-hyoid and sterno-thyroid muscles and to the posterior belly of the omo-hyoid (Fig. 1082).

3. The **thyro-hyoid nerve** (r. thyreohyoideus) is also only an apparent branch of the hypoglossal, as its fibres can be traced back to the cervical plexus. It is given off before the nerve dips beneath the stylo-hyoid muscle and passes down behind the greater cornu of the hyoid bone to reach its distribution to the thyro-hyoid muscle.

4. The **lingual branches** (rr. linguales) with one exception, comprise the real distribution of the hypoglossal. As the nerve lies beneath the mylo-hyoid muscle filaments are given off to the hyo-glossus, the stylo-glossus and the genio-hyoideus. The fibres going to the genio-hyoid are in all probability derived from the cervical plexus and are not of true hypoglossal origin. After giving off the above-named branches, the hypoglossal nerve breaks up into the terminal filaments which pierce the genio-hyo-glossus to supply it and the lingualis muscle.

Variations.—Occasionally the hypoglossal has been found to possess a posterior root bearing a ganglion. This condition is to be regarded as a persistence of the temporary embryonal stage during which the nerve is provided with a posterior root and a ganglion of Froriep (page 1380). In one case the superficial origin was located at the posterior aspect of the medulla. Quite frequently the vertebral artery passes between the rootlets of origin and in rare instances behind them. Sometimes a cross filament, situated either between the genio-hyoglossus and genio-hyoid muscles or in the substance of the latter connects the two hypoglossal nerves. Rarely the hypoglossal has been seen to send a filament to the mylo-hyoid, the digastric or the stylo-hyoid muscle. Occasionally the r. descendens hypoglossi seems to be derived, either entirely or in part, from the vagus, but in these instances the fibres can be traced back to their true origin from the cervical nerves. A filament from the descending nerve sometimes passes into the thorax, where it joins the vagus or the sympathetic; in such cases the aberrant branch is probably derived originally from either the sympathetic or the vagus. The r. descendens hypoglossi may send a branch to the sterno-mastoid muscle.

Practical Considerations.—Involvement of the hypoglossal nerve, usually together with other cranial nerves is frequent in bulbar disease. The most characteristic symptom is a deviation of the tongue, when protruded to the affected side, caused

by the unopposed action of the muscles of the opposite side. The nerve may be injured by operative or other wounds in the submaxillary region or in the mouth, as in gun-shot wounds. It can be easily reached in the submaxillary region by the same incision as that used for ligating the lingual artery (page 736). It passes forward to the tongue, just above the hyoid bone, and forms the upper boundary of the small "lingual triangle," which is exposed when the submaxillary gland is elevated.

THE SPINAL NERVES.

The cranial or cerebral division of the nerves having been considered, the spinal group next claims attention, the visceral or splanchnic (sympathetic) nerves being reserved for a final and separate description.

The spinal nerves (**nn. spinales**) include a series of usually thirty-one pairs of symmetrically disposed trunks which pass laterally from the spinal cord and emerge from the vertebral canal through the intervertebral foramina (Fig. 880). Each nerve arises from the cord by a dorsal *sensory* and a ventral *motor root*, which separately traverse the subarachnoid and subdural spaces and evaginate or pierce the pia mater, arachnoid and dura mater. Within the intervertebral foramina the roots unite to form a common trunk, which carries with it a sheath composed of the three membranes, the contribution of the arachnoid and pia, however, soon ending, whilst the dural covering is prolonged to become continuous with the epineural sheath of the nerve.

Nomenclature.—The spinal nerves are designated not relative to the position at which they arise from the cord, but according to their point of emergence from the vertebral canal. They are divided, therefore, into the *cervical*, *thoracic*, *lumbar*, *sacral* and *coccygeal* groups. With the exception of those in the cervical region, the individual nerves are named according to the vertebra below which they emerge from the vertebral canal. On account of the disproportion between the eight cervical nerves and the seven cervical vertebræ, this arrangement necessarily can not prevail in the neck. The first cervical nerve, often called the *suboccipital nerve*, emerges between the occipital bone and the atlas ; the second emerges below the first vertebra, the third below the second and so on down to the eighth, which traverses the foramen between the seventh cervical and first thoracic vertebral segments.

Constitution.—Every spinal nerve arises by two roots, a posterior sensory and an anterior motor, the latter being composed of the axones proceeding from the motor neurones situated within the gray matter of the anterior cornu of the spinal cord, whilst the fibres composing the posterior or sensory root are the axones of the neurones within the ganglia which are invariably present on these roots. The formation of the common trunk, by the union of the two roots, affords opportunity for the two varieties of fibres to intermingle, so that the anterior and posterior primary divisions into which the common trunk divides contain both sensory and motor fibres. In addition to these fibres, which are destined for the somatic muscles and the integument, others are added from the sympathetic neurones for the supply of the outlying involuntary muscle and glandular tissue occurring in the regions to which the spinal nerves are distributed. It is evident, therefore, that the terms "motor" and "sensory," as applied to the somatic branches of the spinal nerves, are relative and not absolute, since in all cases the nerves passing to the muscles contain sensory and sympathetic fibres in addition to those ending as motor filaments in relation with the striated muscle fibres. Likewise, in the case of the sensory branches distributed to the integument, sympathetic filaments (motor to the involuntary muscle of the blood-vessels and secretory to the glands) accompany those concerned in collecting sensory impulses. On the other hand, where they retain their typical plan, as in the case of the thoracic nerves, the spinal nerves contribute motor fibres which end around the sympathetic neurones to supply motor impulses either to the involuntary muscle of the organs, by way of the splanchnic efferents, or to the outlying involuntary muscle along the somatic nerves in the manner above described.

The **sensory, posterior** or **dorsal roots** (**radices posteriores**) of the spinal nerves are usually larger than the motor, a condition due to the increased number of their filaments and the greater size of those filaments (**fila radicularia**). The fasciculi which form the sensory root are attached to the cord along the postero-lateral

groove as a continuous series, called the *posterior root zone* (Fig. 884). These rootlets are sometimes so numerous and so crowded, that those of adjacent nerves overlap and adhere to one another. Where more typically disposed, as in the thoracic region, the cord-segments (page 1024) are distinct. The fasciculi for any one nerve usually collect into two bundles which pass to the proximal aspect of the spinal ganglion.

The **spinal ganglia** (gg. spinalia) are aggregations of nerve-cells found on the posterior roots of all the spinal nerves (Fig. 852). They are usually ovoid in shape, from 4–6 mm. in length, and are occasionally bifid at their proximal ends. They consist of a cluster of unipolar neurones, whose centrally directed axones form the sensory root of the spinal nerve and whose dendrites extend peripherally as the sensory distribution. The ganglia are usually situated in the intervertebral foramina, but exceptions to this rule are presented by the ganglia of the first and second cervical nerves, which lie upon the neural arches of the atlas and axis respectively, and by those of the sacral and coccygeal nerves, which are lodged within the vertebral canal. Although situated beyond the dural sheath of the cord, with the exception of the ganglion of the coccygeal nerve, they are invested by a prolongation of it.

Variations.—The first cervical nerve may either have no posterior root or may derive it from or share it with the eleventh cranial nerve. Its ganglion may be very rudimentary or entirely absent. Considerable variation is found in the thoracic region, where either the anterior or posterior or both roots of one of the nerves may seemingly be absent. In the lumbar and upper sacral nerves the ganglion may be double, each bundle of the posterior root having its own.

Ganglia aberrantia are small detached portions of the spinal ganglia occasionally found along the posterior roots of the upper cervical, the lumbar and the sacral nerves.

The **motor, anterior** or **ventral roots** (radices anteriores) are smaller than the posterior and have no ganglia. They emerge from the anterior surface of the cord in a series of fasciculi (fila radicularia), the *anterior root-zone*, with a tendency to form two groups which unite in the completed root (Fig. 878). As in the posterior roots, the fasciculi of origin may overlap one another or fuse with those of adjoining nerves.

Number.—As usually found the thirty-one pairs are grouped as follows:—eight cervical, twelve thoracic, five lumbar, five sacral and one coccygeal.

Variations.—Should there be any anomaly in the number or arrangement of the vertebræ, there is a corresponding modification of the nerves. The greatest variation occurs in the coccygeal region. There may be none at all in this situation, or one or two additional ones may be found. Traces of two extra ones, which are rudimentary caudal nerves, may be found in the filum terminale.

Size.—The largest spinal nerves are those which are concerned in the formation of the limb plexuses—brachial, lumbar and sacral—and are, therefore, the lower cervical, the first thoracic, the lower lumbar and the upper sacral. The largest nerves in the entire series are the lower lumbar and upper sacral. The smallest are the lower sacral and the coccygeal. Those of the upper cervical region are smaller than those of the lower, the sixth being the largest of those in the neck. With the exception of the first, the thoracic nerves are comparatively small.

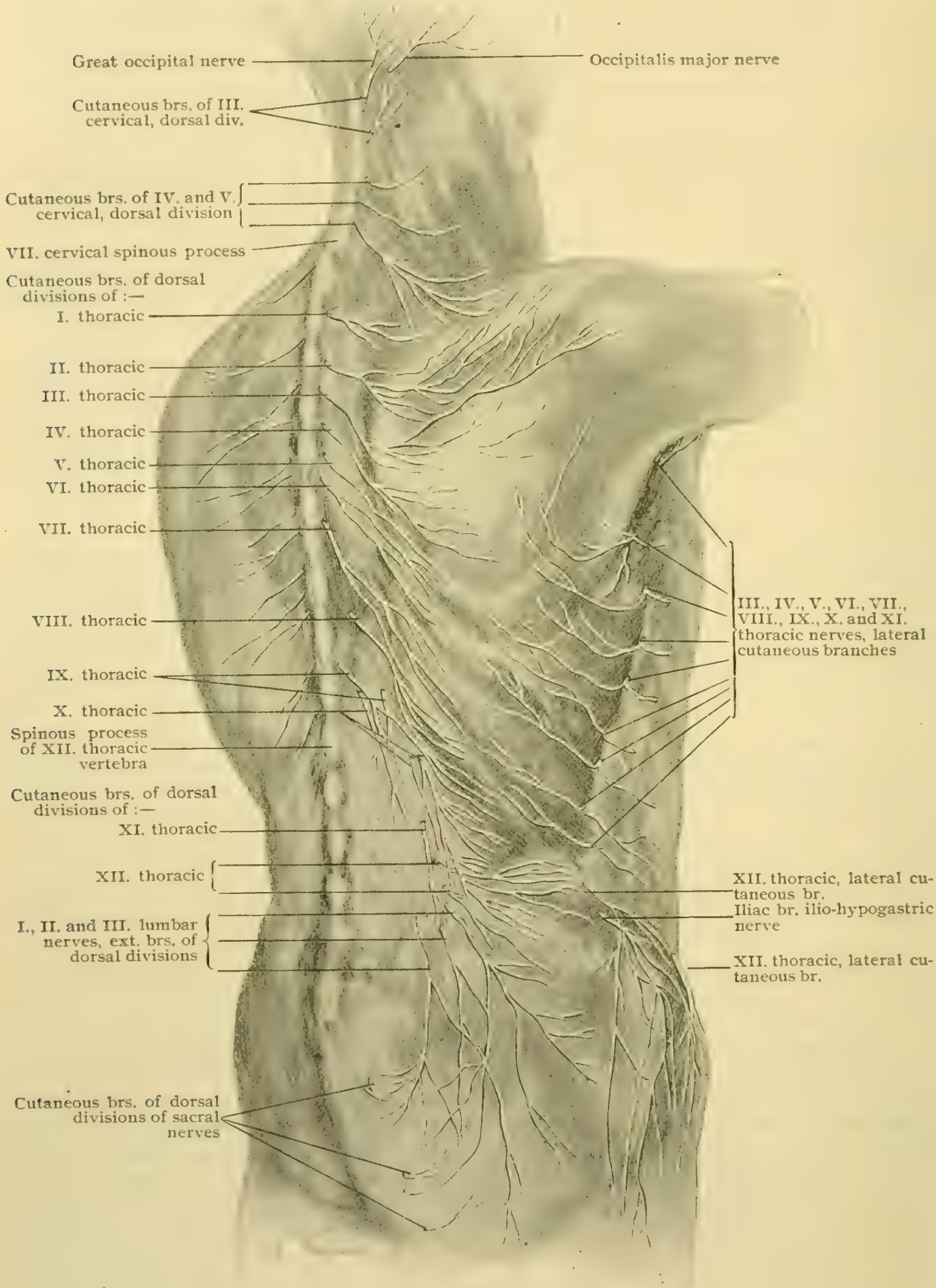
Divisions.—The common trunk formed by the union of the two roots emerges from its intervertebral foramen and almost immediately gives off a *meningeal* or *recurrent branch* (r. meningeus). This tiny nerve is joined by a filament from a gray ramus communicans and enters the vertebral canal through the foramen to be distributed to the vertebræ and their ligaments, and to the blood-vessels of the vertebral canal and of the spinal cord and its membranes. After giving off the recurrent twig, each trunk soon splits into two branches, called the *anterior* and *posterior primary divisions* (rr. anterior et posterior), each of which is composed of fibres from both roots (Fig. 1085), as well as of sympathetic filaments.

THE POSTERIOR PRIMARY DIVISIONS OF THE SPINAL NERVES.

The posterior primary divisions (rr. posteriores) of the spinal nerves are as a rule smaller than the anterior (rr. anteriores). They arise either as a single cord from the trunk formed by the union of the two roots, or as two separate strands

from the roots themselves. They turn dorsally almost immediately and divide into an internal (r. medialis) and an external branch (r. lateralis), which supply the

FIG. 1083.



Superficial dissection, showing cutaneous branches of posterior divisions and lateral cutaneous branches of anterior divisions of spinal nerves.

dorsal muscles and integument. At the two extremities of the spinal series the division into internal and external branches does not prevail, the first cervical,

the fourth and fifth sacral and the coccygeal nerve failing in this respect. Down to and including the sixth thoracic nerve, the internal branches are mainly cutaneous and the external entirely muscular. From the seventh thoracic down, the reverse condition exists. In the former region the internal branches become cutaneous near the spine, whilst in the latter the sensory filaments pass laterally for some distance through the muscles before reaching their cutaneous distribution.

THE CERVICAL NERVES.

The **first cervical nerve** (**n. suboccipitalis**), the first of the spinal series, is atypical in several respects. Its posterior root is either insignificant or entirely absent, and its posterior division, which does not divide into internal and external branches, is larger than the anterior and usually does not send off any direct cutaneous branch. The nerve passes dorsally between the occipital bone and the posterior arch of the atlas and traverses the suboccipital triangle, occupying a position below and posterior to the vertebral artery. Superficial to it is the complexus muscle.

Branches.—These are: (1) the *muscular*, (2) the *communicating* and (3) the *cutaneous*.

1. The *muscular branches* supply the superior and inferior oblique, the complexus and the rectus capitis posticus major and minor muscles.

2. The *communicating branch* forms a loop with the second cervical nerve. It usually arises in common with the twig to the inferior oblique muscle, through or over which muscle it passes to reach its destination. It may arise with the nerve to the complexus, after piercing which muscle it communicates with the great occipital nerve.

In the neck and close to the vertebræ is a series of loops between the posterior divisions of the first, second, third and sometimes the fourth cervical nerves. This is called the *posterior cervical plexus* and from it filaments are distributed to the neighboring muscles.

3. The *cutaneous branch* is not always present. It accompanies the occipital artery, inosculates with the small and great occipital nerves and supplies the occipital region.

The **second cervical nerve** is distinguished by the size of its posterior division, (**r. posterior**) which is larger than the anterior (**r. anterior**). Its posterior division takes a dorsal course between the atlas and the axis, and then between the inferior oblique and semispinalis colli muscles. Reaching the deep surface of the complexus it breaks up into its *external portion* (**r. lateralis**), which supplies the complexus, obliquus inferior, semispinalis colli and multifidus spinæ muscles, and its *internal portion* (**r. medialis**). The latter is called the *great occipital nerve* (**n. occipitalis major**). This nerve (Fig. 1087) passes upward over the inferior oblique, pierces the complexus and trapezius, and accompanies the occipital artery to the scalp, to the posterior half of which it is the main sensory nerve. It becomes superficial at the superior nuchal line, at a point from 2–3 cm. lateral to the external occipital protuberance, and spreads out into numerous branches which supply the scalp as far forward as the vertex.

The great occipital nerve **communicates** with the small and least occipital and the posterior and great auricular nerves.

Variations.—An approximate balance is maintained between the great and small occipital nerves, any deficiency in the distribution of either usually being equalized by a compensatory enlargement of the other. Sometimes the great occipital sends a branch to the auricle. The external branch may give off a cutaneous filament or may furnish a twig to the superior oblique.

The **third cervical nerve** has a smaller posterior division than has the second. Passing backward, the former helps to form the posterior cervical plexus and divides into external and internal branches. The *external* branch (**r. lateralis**) supplies adjacent muscles and the *internal* branch (**r. medialis**), known as the *least* or *third occipital nerve* (**n. occipitalis tertius**), pierces the complexus, splenius and trapezius to supply the skin of the occipital and posterior cervical regions (Fig. 1083).

In addition to assisting in the formation of the posterior cervical plexus it communicates with the great occipital nerve.

The **fourth, fifth, sixth, seventh and eighth cervical nerves** have quite small posterior primary divisions (**rr. posteriores**). The fourth, fifth and sixth divide into the usual external and internal branches (**rr. laterales et mediales**), which supply respectively the adjacent muscles and the dorsal integument. The seventh and eighth usually have no cutaneous branches and are distributed solely to the deeper muscles of the back.

A communicating filament from the fourth may aid in the formation of the posterior cervical plexus.

Variations.—The cutaneous branches of the fifth and sixth may be very small or absent entirely.

THE THORACIC NERVES.

The posterior primary divisions (**rr. posteriores**) of the thoracic or dorsal nerves (**nn. thoracales**) follow the general arrangement of dividing into external and internal branches. Of these the internal branches of the upper six are mainly cutaneous and the external entirely muscular. In the lower six, on the contrary, the external branches are principally cutaneous and the internal entirely muscular.

The **external branches** (**rr. laterales**) gradually increase in size from above downward. They pierce or pass under the longissimus dorsi to reach the interval between that muscle and the ilio-costalis, eventually reaching and supplying the erector spinæ. Those from the lower half of the thoracic nerves distribute sensory fibres for the supply of the skin overlying the angles of the ribs (Fig. 1083).

The **internal branches** (**rr. mediales**) of the upper six or seven pass dorsally between the multifidus spinæ and semispinalis muscles. After innervating the transverso-spinales they become superficial close to the median dorsal line and supply the skin of the back, sometimes extending laterally beyond the vertebral border of the scapula. The internal branches of the lower nerves traverse the interval between the longissimus dorsi and the multifidus spinæ and supply the latter muscle.

Variations.—The sixth, seventh and eighth thoracic nerves may give off cutaneous twigs from both external and internal branches. The first thoracic nerve may have no cutaneous branch.

THE LUMBAR NERVES.

The posterior primary divisions (**rr. posteriores**) of the lumbar nerves (**nn. lumbales**) divide into the usual external and internal branches.

The **external branches** (**rr. laterales**) of all five lumbar nerves enter and supply the erector spinæ, those of the lower two terminating there. From the external branches of the first, second and third arise cutaneous offshoots (**nn. clunium superiores**) of considerable size (Fig. 1083). These pierce the ilio-costalis and the aponeurosis of the latissimus dorsi above the crest of the ilium and supply the skin of the gluteal region as far forward as the great trochanter. From the fifth a branch passes downward to inosculate with a similar branch of the first sacral nerve to aid in the formation of the posterior sacral plexus.

The **internal branches** (**rr. mediales**) turn directly backward and supply the multifidus spinæ muscle.

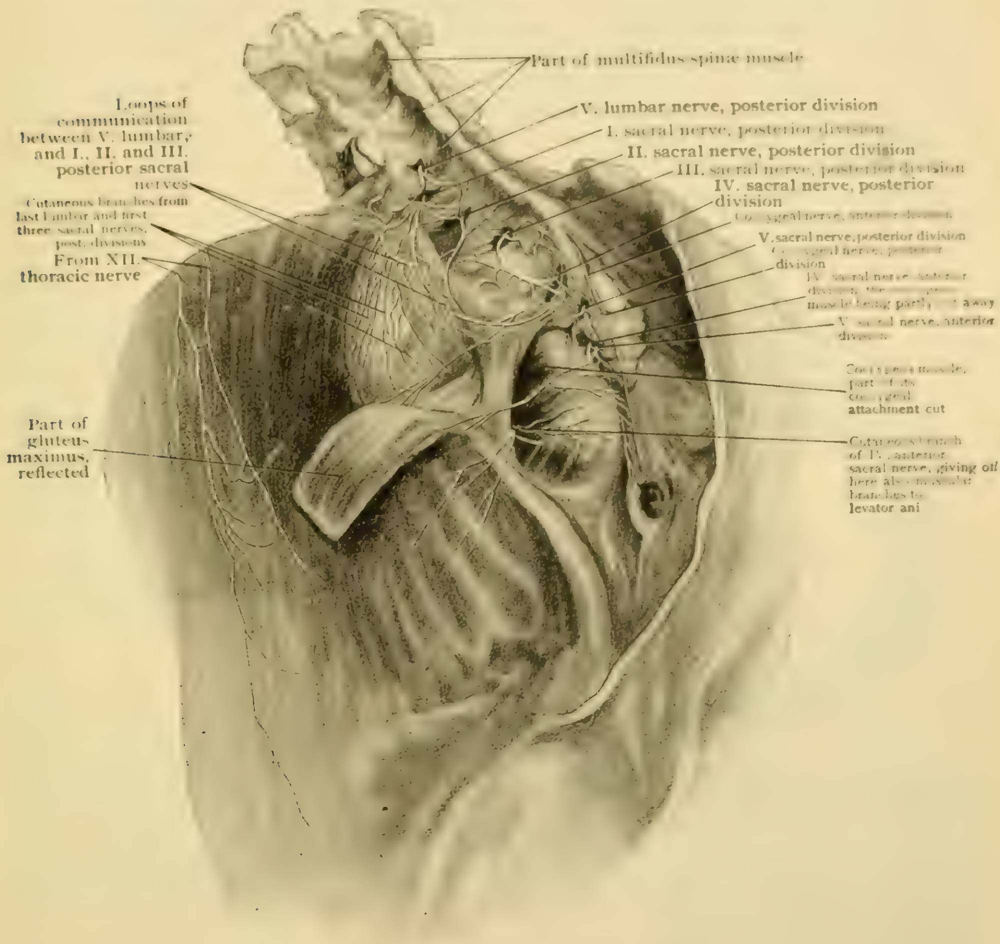
THE SACRAL NERVES.

The posterior primary divisions (**rr. posteriores**) of the sacral nerves (**nn. sacrales**), with the exception of that of the fifth, emerge from the vertebral canal through the posterior sacral foramina. The first, second and third pass outward under cover of the multifidus spinæ and divide into external and internal branches.

The **external branches** (**rr. laterales**) of the first, second and third sacral nerves unite over the upper part of the sacrum with a similar branch of the fifth lumbar and with the fourth sacral nerve to form a series of loops, the **posterior sacral plexus**

(Fig. 1084). From this structure branches pass laterally till they reach the interval between the great sacro-sciatic ligament, which they pierce, and the deep surface of the gluteus maximus, where they form a second series of loops. From the primary loops branches are supplied to the multifidus spinæ and from the secondary loops proceed two or more filaments, usually two (**nn. clunium medii**), which pierce the gluteus maximus on a line connecting the posterior superior spine of the ilium

FIG. 1084.



Dissection showing left posterior sacral plexus.

and the tip of the coccyx. One is usually situated near the lower portion of the sacrum and the other at the side of the coccyx. They pass laterally and supply the skin of the buttock (Fig. 1083).

The **internal branches** (**rr. mediales**) of the first, second and third sacral nerves are small in size and are distributed to the multifidus spinæ.

The posterior primary divisions of the fourth and fifth sacral nerves are of small size. They pass below the multifidus spinæ and continue as single trunks, not breaking up as do the others, into two branches. They are connected with each other and with the coccygeal nerve by loops which form the **posterior sacro-coccygeal nerve.** From this structure fibres which pierce the great sacro-sciatic ligament are given off to be distributed to the integument in the coccygeal region (Fig. 1084).

THE COCCYGEAL NERVE.

The posterior primary division (r. **posterior**) of the coccygeal nerve (n. **coccygeus**) does not divide into internal and external branches. It unites with the fourth and fifth sacral to form the posterior sacro-coccygeal nerve, whose course and distribution are described above.

THE ANTERIOR PRIMARY DIVISIONS OF THE SPINAL NERVES.

The anterior primary divisions (rr. **anteriores**) of the spinal nerves, like the posterior (rr. **posteriores**), contain fibres from both the anterior and posterior roots and, with the exception of those of the first and second cervical nerves, are larger than the posterior. After liberation from the main trunk at the intervertebral foramina, they pass ventrally and supply the lateral and anterior portions of the neck and trunk, as well as the limbs.

Shortly after leaving its foramen, each anterior division is joined by a slender fasciculus from the gangliated cord of the sympathetic, called the *gray ramus communicans* (page 1357). Branches to the sympathetic system are given off from some of the thoracic, lumbar and sacral nerves, in the shape of small fasciculi of medullated fibres, called the *white rami communicantes.* These are destined for the various structures of the splanchnic area and constitute the *visceral* or *splanchnic distribution* of the spinal nerves. The remainder of the fibres are supplied to the body wall and extremities and constitute the *somatic distribution* of the nerves.

FIG. 1085.

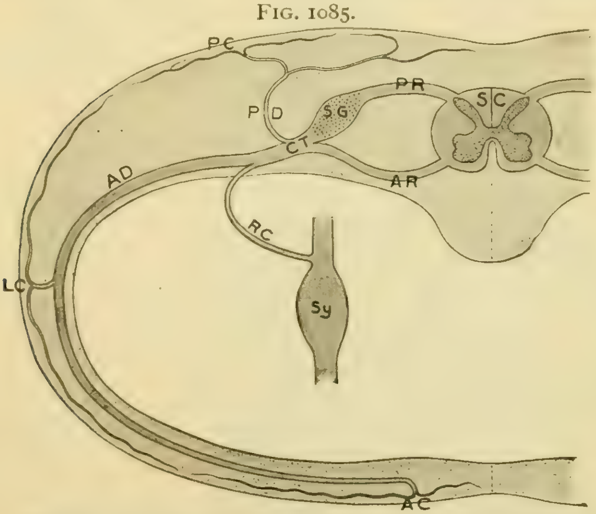


Diagram illustrating constitution and division of typical spinal nerve; *SC*, spinal cord; *AR*, *PR*, anterior and posterior roots; *SG*, spinal ganglion; *CT*, common trunk; *AD*, *PD*, anterior and posterior primary divisions; *PC*, *LC*, *AC*, posterior, lateral and anterior cutaneous branches; *RC*, ramus communicans; *Sy*, sympathetic ganglion and cord.

In the case of the cervical, first and sometimes second thoracic, lumbar, sacral and coccygeal nerves, plexuses of a greater or less degree of intricacy are interposed between the origin and distribution of the nerves. This renders the tracing of any set of fibres a matter of extreme difficulty, but in the greater portion of the thoracic region the original segmental and less complex arrangement persists.

A typical spinal nerve (Fig. 1085), such as one of those in the mid-thoracic region, is arranged as follows. The constitution of the main trunk (page 1278) and the distribution of its posterior branch (page 1279) have already been described. The anterior primary division (r. **anterior**) leaves the intervertebral foramen and almost immediately is connected with the gangliated cord by gray and white rami communicantes. It then enters an intercostal space through which it courses between the external and internal intercostal muscles, both of which it supplies. At the side of the chest it gives off a *lateral cutaneous branch* (r. **cutaneus lateralis**), which distributes a few tiny motor twigs and then pierces the external intercostal muscle to supply the skin over the lateral portion of the trunk. On reaching the superficial fascia it usually breaks up into two branches, a larger *anterior* (r. **anterior**) and a smaller *posterior* (r. **posterior**). Having given off the lateral cutaneous branch, the main anterior primary division continues its forward course nearly to the mid-line, where it pierces the muscle and becomes superficial as the *anterior terminal cutaneous branch* (r. **cutaneus anterior**).

The integument is therefore supplied, from dorsal to ventral mid line, by the posterior primary division, the posterior and anterior divisions of the lateral cutaneous branch and the anterior cutaneous branch of the anterior primary division. The muscles derive their nerve-supply from both the anterior and the posterior primary divisions.

THE CERVICAL NERVES.

The anterior primary divisions (**rr. anteriores**) of the eight cervical nerves (**nn. cervicales**), assisted by the first and second thoracic, supply the head, neck, upper extremity, thoracic integument and diaphragm. The first, second, third and fourth communicate freely and form the *cervical plexus* for the supply of the head and neck and the skin of the upper pectoral and shoulder regions, whilst the fifth, sixth, seventh, and eighth, aided by the first and sometimes by the second thoracic, form the *brachial plexus*, which supplies the upper extremity and the lateral thoracic wall.

THE CERVICAL PLEXUS.

The cervical plexus (**plexus cervicalis**) is formed by the union of the anterior primary divisions (**rr. anteriores**) of the upper four cervical nerves (Fig. 1086). After traversing the intervertebral foramina, they pass behind the vertebral artery and emerge, the first between the rectus capitis lateralis and the rectus capitis anticus minor muscles, and the others first between the intertransversales muscles and then between the rectus capitis anticus major and scalenus medius muscles. Each is joined by a gray ramus communicans, derived either from the superior cervical ganglion of the sympathetic or from the association cord between the superior and middle cervical ganglia. Under cover of the sterno-mastoid the four nerves are connected to form the cervical plexus. The second, third and fourth each divide into an ascending and a descending branch; the first does not divide.

FIG. 1086.

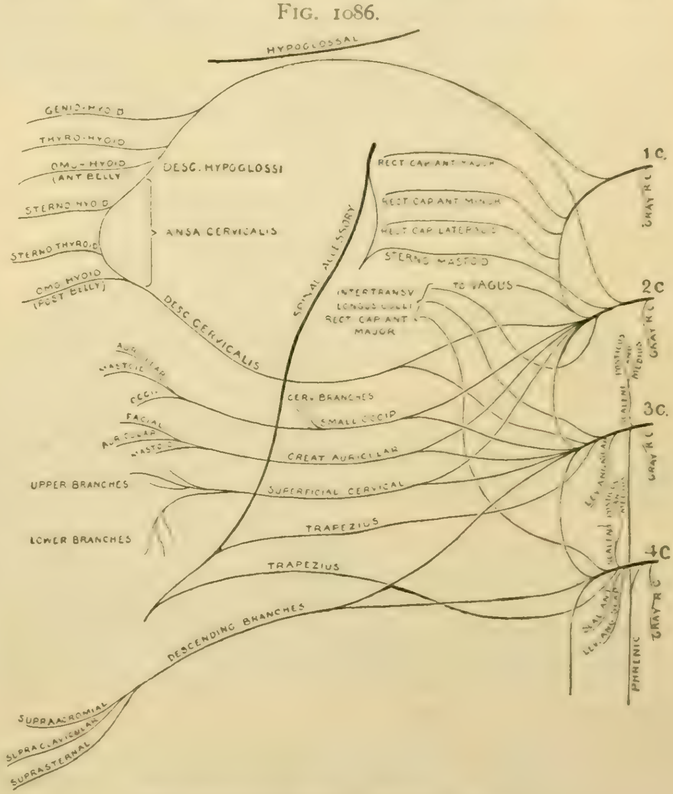


Diagram illustrating plan of cervical plexus.

These branches are connected in an irregular series of loops that constitute the cervical plexus, which lies opposite the first four cervical vertebræ and upon the scalenus medius and levator anguli scapulæ muscles, and is covered by the sterno-mastoid.

Branches.—The branches of the plexus may be divided into a *superficial* and a *deep* set. The former reach the under surface of the deep fascia at about the middle of the posterior margin of the sterno-mastoid and are distributed to the integument of the head, neck, shoulder and upper pectoral region. The latter are divided into an internal and an external group, some of which supply the muscles of the neck

and the diaphragm, whilst others communicate with the ninth, eleventh and twelfth cranial and the sympathetic nerves.

THE CERVICAL PLEXUS.

I. Superficial Branches.
- A. Ascending branches :
  - 1. Small occipital
  - 2. Great auricular
- B. Transverse branch :
  - 3. Superficial cervical
- C. Descending branches :
  - 4. Suprasternal
  - 5. Supraclavicular
  - 6. Supraacromial

II. Deep Branches.
- D. External branches :
  - 7. Muscular
  - 8. Communicating
- E. Internal branches :
  - 9. Muscular
  - 10. Phrenic
  - 11. Communicating

I. The **superficial branches** are purely sensory. They become superficial at the posterior border of the sterno-mastoid, slightly above its middle, and from that point radiate in all directions to reach their cutaneous destinations (Fig. 1087).

1. The **small occipital nerve** (n. occipitalis minor) (Fig. 1087) may be either single or double. It originates from the second and third cervical nerves, or from the second only, and passes backward and upward beneath the deep fascia along or overlapping the posterior border of the sterno-mastoid muscle, where it gives off (*a*) the *cervical branches*. It pierces the deep fascia at the upper angle of the occipital triangle and breaks up into its terminal branches : (*b*) the *auricular*, (*c*) the *mastoid* and (*d*) the *occipital*.

a. The **cervical branches** are tiny twigs which supply the skin over the upper part of the occipital triangle.

b. The **auricular branch** supplies the integument over the cranial aspect of the posterior part of the pinna.

c. The **mastoid branch** supplies the scalp overlying and above the mastoid process.

d. The **occipital branch** is distributed to the area of scalp of the occiput lying between the mastoid process and the distribution of the great occipital nerve.

The small occipital **communicates** with the posterior and great auricular nerves and with the great occipital.

Variations.—The small occipital varies in size and may be so small as to be distributed only to the integument in the neck. In such an event, and usually in case of any deficiency, the unsupplied area receives fibres from the great occipital. It sometimes passes backward instead of upward and pierces the trapezius near the upper border before reaching the scalp.

2. The **great auricular nerve** (n. auricularis magnus) (Fig. 1087) is the largest of the superficial set and arises, usually with the superficial cervical nerve, from the second and third, from the third alone, or from the third and fourth cervical nerves. Turning over the posterior margin of the sterno-mastoid it ascends toward the ear between the platysma and the deep fascia. Below the ear it gives off a few (*a*) *facial twigs* and then terminates by dividing into (*b*) *auricular* and (*c*) *mastoid branches.*

a. The **facial twigs** pass through the parotid gland and over the angle of the mandible, supplying the integument over the parotid gland and masseter muscle and communicating with the cervico-facial division of the seventh cranial nerve.

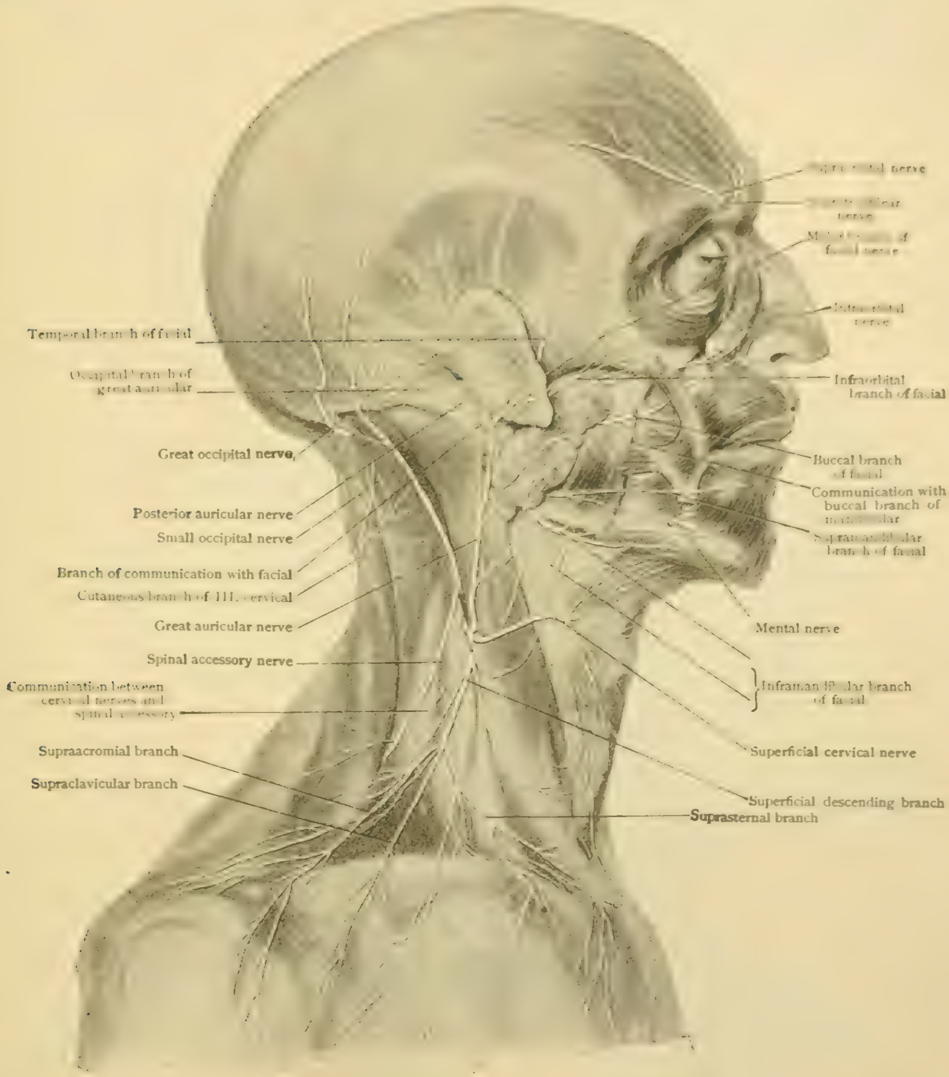
b. The **auricular branches** (r. anterior) supply mainly the cranial surface of the posterior part of the pinna. One filament passes through the cartilage by means of a cleft between the concha and the antihelix and supplies the outer surface, while a few twigs are distributed to the outer surface of the lobule. The auricular branches inosculate with the small occipital and posterior auricular nerves.

c. The **mastoid branch** (r. posterior) is distributed to the skin overlying the mastoid process and the upper part of the sterno-mastoid muscle. It inosculates as does the auricular branch.

Variation.—The mastoid branch may arise independently from the plexus and pass upward to its destination between the small occipital and great auricular nerves.

3. The **superficial cervical nerve** (n. cutaneus colli) usually arises in common with the great auricular from the second and third, the third only, or from the third and fourth cervical nerves (Fig. 1087). From the posterior margin of the sterno-mastoid it passes almost directly forward over the middle of that muscle and under

FIG. 1087.



Dissection showing superficial branches of cervical plexus, as well as parts of trigeminal, facial, spinal accessory and great occipital nerves; ear has been drawn forward.

the platysma myoides and the external jugular vein. It perforates the deep cervical fascia near the anterior border of the sterno-mastoid and divides into (*a*) an *upper* and (*b*) a *lower* set of branches.

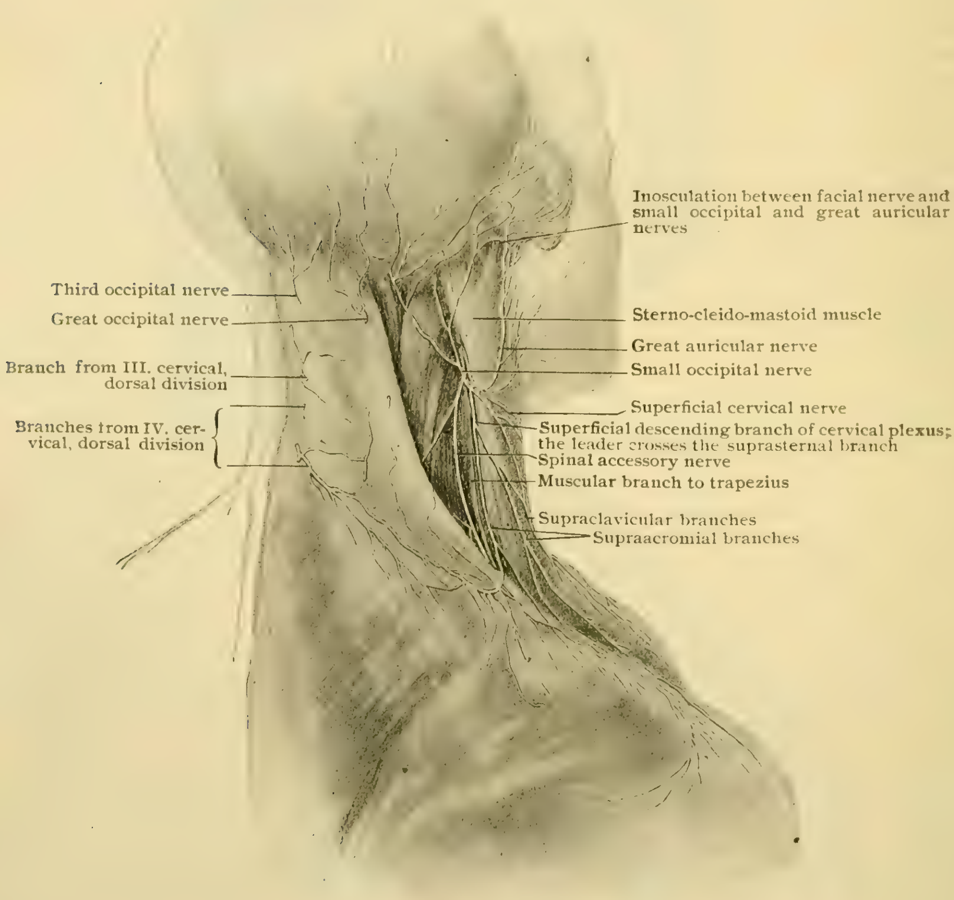
a. The **upper branches** (rr. superiores) form an extensive inosculation with the inframandibular branch of the facial nerve, after which they pierce the platysma and supply the integument of the neck as far forward as the median line and as far up as the inferior margin of the mandible.

b. The **lower branches** (rr. inferiores) after piercing the platysma are distributed to the skin of the lower part of the neck to the mid-line as far down as the sternum.

Variation.—The superficial cervical, instead of a single nerve, may arise as two or more filaments from the cervical plexus.

The **descending branches** (nn. supraclaviculares) (Fig. 1087) arise from the third and fourth cervical nerves and pass downward in the anterior margin of the occipital triangle along the posterior edge of the sterno-mastoid. On nearing the clavicle they break up into three distinct sets: (4) the *suprasternal*, (5) the *supraclavicular* and (6) the *supraacromial*.

FIG. 1088.



Dissection showing superficial branches of cervical plexus and posterior cutaneous branches.

4. The **suprasternal branches** (rr. supraclaviculares anteriores) are the smallest. They pass over the lower end of the sterno-mastoid and the inner end of the clavicle and supply the skin of the chest as far down as the angulus Ludovici. One or two filaments terminate in the sterno-clavicular articulation.

5. The **supraclavicular branches** (rr. supraclaviculares medii) pass across the middle of the clavicle and supply the integument of the chest as far down as the third or fourth rib, inosculating with twigs from the anterior cutaneous branches of the upper thoracic nerves.

Variation.—A twig may perforate the clavicle.

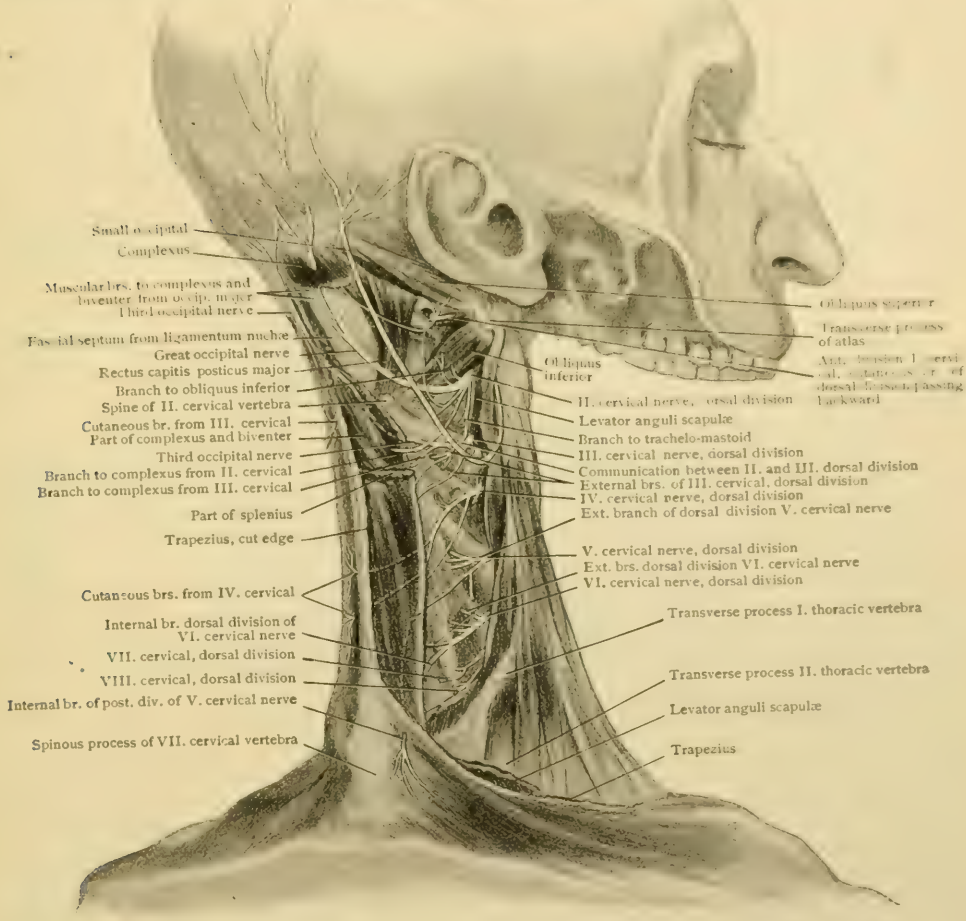
6. The **supraacromial branches** (rr. supraclaviculares posteriores) cross the clavicular insertion of the trapezius and are distributed to the skin over the anterior, external and posterior aspects of the shoulder as far down as the lower portion of the deltoid.

II. The deep branches are divided into two sets, an external and an internal. Both arising beneath the sterno-mastoid, the former pass away from and the latter toward the median line of the neck.

7. The external **muscular branches** are distributed as follows:—

a. The **sterno-mastoid** receives a branch from the second cervical which enters the deep surface of the muscle and interlaces with a branch of the spinal accessory nerve to form the **sterno-mastoid plexus.**

FIG. 1089.



Dissection of right side of neck, showing deeper relations of cervical nerves.

b. The **trapezius** receives fibres from the third and fourth cervical nerves which arise with and accompany the descending branches of the superficial set through the occipital triangle. They dip under the anterior margin of the trapezius, before and after which they form a more or less complex inosculation with the spinal accessory, called the **subtrapezial plexus**, from which filaments are distributed to the trapezius muscle (Fig. 1088).

c. The **levator anguli scapulæ** receives two branches which take their origin from the third and fourth nerves.

d. The **scalenus medius** and (*e*) **scalenus posticus** also receive fibres from the third and fourth.

8. The **communicating branches** form points of contact and union with the spinal accessory nerve (*a*) under the sterno-mastoid and (*b*) in the occipital triangle and under the trapezius. By means of these inosculations are formed the **sterno-mastoid and subtrapezial plexuses.**

9. The **muscular branches** are distributed to (*a*) certain prevertebral muscles and to (*b*) the genio-hyoid and the infrahyoid muscles.

a. The **rectus capitis anticus major** and **minor** and the **rectus capitis lateralis** are supplied by a filament arising from the loop between the first and second cervical nerves. The **intertransversales**, the **longus colli** and a portion of the **rectus capitis anticus major** receive their supply from the second, third and fourth, and the upper part of the **scalenus anticus** receives a twig from the fourth cervical nerve.

b. The **genio-hyoid** and the four muscles of the **infrahyoid group** are innervated by the cervical plexus in a rather roundabout manner. From the first and second cervical nerves are given off one or more branches which join the hypoglossal nerve shortly after its appearance in the neck. These fibres for a time form an integral portion of the hypoglossal and eventually escape from it as the **nerve to the genio-hyoid**, the **nerve to the thyro-hyoid** and the **n. descendens hypoglossi** (Fig. 1082). The last-mentioned nerve leaves the hypoglossal at the point where the latter crosses the internal carotid artery and then descends in the anterior cervical triangle. In front of, or sometimes within, the carotid sheath it forms a loop of communication, called the **hypoglossal loop** or **ansa cervicalis** (**ansa hypoglossi**) by inosculation with the **descending cervical nerve** (**n. descendens cervicalis**) (Fig. 1082). This descending cervical nerve is derived from the second and third cervical nerves and at first consists of two twigs which later unite in front of the internal jugular vein. From this point it passes downward and inward as a single trunk to reach its point of entrance into the ansa hypoglossi. The ansa may be either a simple loop or a plexus and is situated anterior to the carotid sheath at a variable point in the neck. From it branches are given off to the **sterno-hyoid**, the **sterno-thyroid** and the posterior belly of the **omo-hyoid** (Fig. 1076).

10. The **phrenic nerve** (n. phrenicus), although an internal muscular branch of the cervical plexus, is of such importance as to merit a separate description. Whilst mainly the motor nerve to the diaphragm, it contains some sensory fibres ; in this connection it may be pointed out that the phrenic is not the only motor nerve to the diaphragm, the lower thoracic nerves aiding in its innervation. The phrenic arises mainly from the fourth cervical nerve but receives additional fibres from the third and fifth (Fig. 1090). It passes down the neck on the scalenus anticus, which it crosses from without inward, and at the base of the neck accompanies that muscle between the subclavian artery and vein. At the entrance to the thorax it passes over the root of the internal mammary artery from without inward and backward, occupying a position behind the sterno-clavicular articulation and the point of junction of the subclavian and internal jugular veins. It then follows a course almost vertically downward, over the apex of the pleura and through the superior and middle mediastina, to the upper surface of the diaphragm.

The **right phrenic** (Fig. 1090) is shorter than the left on account of its more direct downward course and the greater elevation of the diaphragm on that side. It crosses the second part of the subclavian artery and accompanies the right innominate vein and the superior vena cava on their lateral aspect. It then passes in front of the root of the lung and finishes its course by descending between the lateral aspect of the pericardium and the mediastinal pleura. Nearing the diaphragm it breaks up at the antero-lateral aspect of the quadrate foramen into its terminal branches, a few of which enter the abdomen through this opening.

The **left phrenic** (Fig. 1090), having to wind around the left side of the heart and reach the more inferior half of the diaphragm, is longer than its fellow, about one-seventh longer (Luschka). Entering the thorax between the subclavian artery and the left innominate vein it crosses the anterior face of the left vagus nerve and continues its downward course by passing over the left side of the aortic arch. Reaching the middle mediastinum it courses in front of the root of the lung, behind the lower left angle of the pericardium, and descends to the diaphragm between the pericardium and the mediastinal pleura. It breaks up into its terminal branches before arriving at the thoracic surface of the diaphragm, which it enters at a point further from the median line and more anterior than does the right.

Branches of the phrenic nerve are : (*a*) the *pleural*, (*b*) the *pericardiac* and (*c*) the *terminal*.

a. The **pleural branches**, two in number, are almost microscopic in size, and are given off as the nerve crosses the apex of the pleura. One supplies the costal pleura and the other, which sometimes accompanies the internal mammary artery, is distributed to the mediastinal pleura.

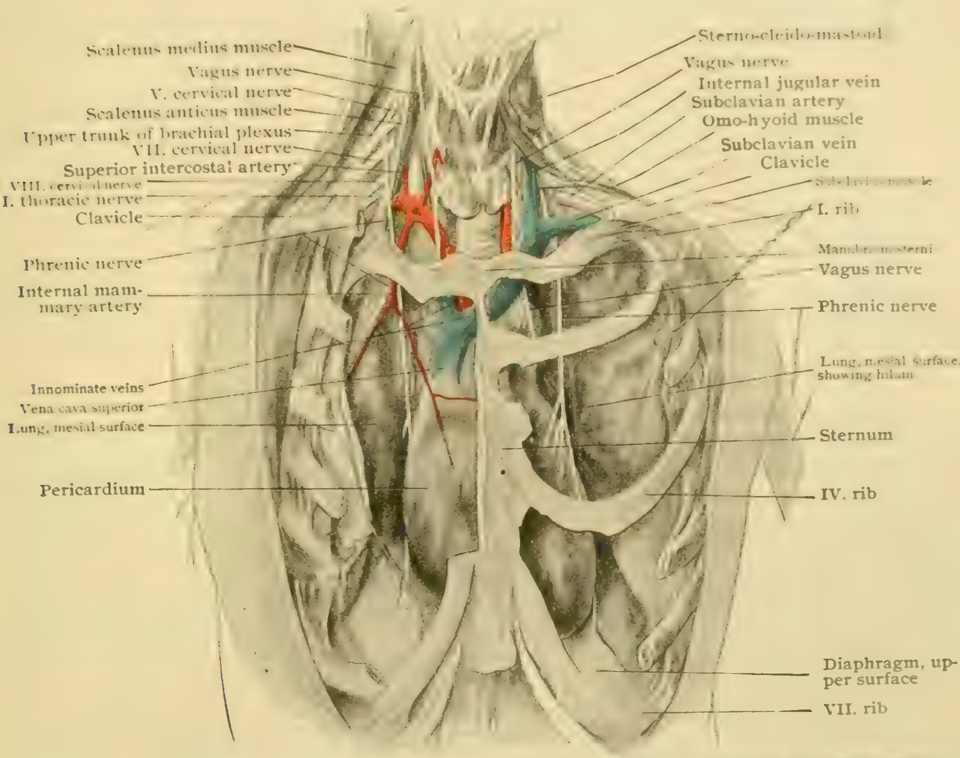
b. The **pericardiac branch** (r. pericardiacus) is a tiny filament which is usually given off opposite the lower margin of the third costal cartilage. It is sometimes absent on the left side.

c. The **terminal branches** arise under cover of the pleura and differ to some extent on the two sides.

The *right phrenic* divides antero-lateral to the opening for the inferior vena cava into (*aa*) an anterior and (*bb*) a posterior branch.

aa. The *anterior branch* breaks up under the pleura into five or six fine twigs, which spread out antero-laterally in the sternal portion and the anterior part of the right costal portion of the

FIG. 1090.



Dissection showing phrenic nerves; parts of sternum and ribs have been removed; lungs are pulled aside; pericardium is undisturbed.

diaphragmatic musculature. Tiny filaments traverse the interval between the sternal and costal portions and enter the abdomen, where they are distributed to the peritoneal covering of the diaphragm and to the falciform ligament of the liver in the direction of the umbilicus.

bb. The *posterior branch* pierces the central tendon at the outer margin of the quadrate opening and divides into a *muscular* branch and the right *phrenico-abdominal branch* (r. phrenicoabdominalis dexter). The former supplies the lumbar portion of the musculature of the diaphragm. The latter traverses the quadrate foramen and first gives off a recurrent branch which accompanies the inferior vena cava back to the right auricle. After giving off this branch, under cover of the peritoneum some of its fibres enter the *diaphragmatic ganglion* and others unite with filaments from the cœliac plexus to form at the inferior surface of the diaghragm the **diaphragmatic plexus**, which is joined by twigs from the diaphragmatic ganglion. From this plexus fibres are distributed to the coronary ligament and peritoneum of the liver and to the right suprarenal body.

The *left phrenic* pursues a general antero-lateral course and pierces the diaphragm at the junction between the musculature and the central tendon. Under cover of the peritoneum it splits up into an anterior, a lateral and a posterior branch. The *anterior branch* supplies the muscle of the left sternal portion and the antero-lateral part of the left costal portion. The

lateral branch supplies the corresponding part of the left costal portion. The *posterior branch* (r. phrenicoabdominalis sinister) is distributed to the left lumbar portion of the muscle of the diaphragm and usually either a filament passes to the left semilunar ganglion or several small threads to the cœliac plexus, one of which can be traced to the left suprarenal body.

The phrenic nerve **communicates** in the lower part of the neck with the middle or inferior cervical ganglion of the sympathetic. At the inferior aspect of the diaphragm it communicates, on the right side, with the diaphragmatic plexus of the sympathetic and, on the left side, with the semilunar ganglion or the cœliac plexus.

Variations.—The phrenic may receive additional roots from the nerve to the subclavius, the nerve to the sterno-hyoid, the second or the sixth cervical nerve, the n. descendens cervicalis or the ansa hypoglossi. It may arise exclusively from the nerve to the subclavius or, arising normally, may give a branch to that muscle. It sometimes passes along the lateral border of or pierces the scalenus anticus muscle. Instead of descending behind the subclavian vein it may pass anterior to it or even through a foramen in it.

The **accessory phrenic nerve** arises either from the fifth alone or from the fifth and sixth cervical nerves and, entering the thorax either anterior or posterior to the subclavian vein, joins the phrenic at the base of the neck or in the thorax.

II. The **communicating branches** of the internal set effect unions with (*a*) the sympathetic, (*b*) the vagus and (*c*) the hypoglossal.

a. The **superior cervical ganglion of the sympathetic** or the association cord connecting the superior and middle ganglia sends gray rami communicates to the first, second, third and fourth cervical nerves.

b. The **ganglion of the trunk of the vagus** is sometimes connected by means of a tiny nerve with the loop between the first and second cervical nerves.

c. The **hypoglossal nerve** receives, just below the anterior condyloid foramen, a good sized branch from the loop between the first and second cervical nerves. This communication furnishes sensory fibres to the hypoglossal nerve which subsequently leaves the latter as its meningeal branch; other spinal fibres leave the twelfth as the n. descendens hypoglossi and as the nerves to the genio-hyoid and thyro-hyoid muscles.

Practical Considerations.—Of the *motor nerves* of the cervical plexus the *phrenic* is most commonly the seat of trouble and this may result in or be associated with spasm or paralysis of the diaphragm. The involvement of the diaphragm may be part of a progressive muscular paralysis, as from lead poisoning, or from injuries or diseases of the spine. The nerve may be compressed by tumors or abscesses of the neck, or be injured in wounds of the neck. It passes downward under the sterno-mastoid muscle and on the scalenus anticus, from about the level of the hyoid bone. It is covered and somewhat fixed by the layer of deep fascia covering the scalenus anticus muscle. The clonic variety of spasm, singultus or hiccough, is very common, and is occasionally though rarely dangerous by preventing rest and sleep; it may complicate apoplexy, peritonitis or chronic gastric catarrh.

If only one phrenic is paralyzed the disturbance of function is slight and not easily recognized. In a bilateral paralysis, as from alcoholic neuritis, respiration depends almost entirely on the intercostal muscles, since the diaphragm is completely paralyzed. Dyspnœa, therefore, occurs on slight exertion. The epigastrium is depressed rather than prominent and the lower border of the liver is drawn upward.

The *superficial branches* of the cervical plexus emerge together through the deep fascia near the middle of the posterior border of the sterno-mastoid muscle, and from this point pass in various directions. The auricularis magnus passes upward and forward over the sterno-mastoid to the ear and parotid gland, the occipitalis minor along the posterior margin of the same muscle to the scalp, and the superficial cervical branch obliquely forward and upward to the submaxillary region. The descending branches are three in number and pass respectively in the direction of the sternum, clavicle and acromion. They give rise to little or no disturbance when wounded.

THE BRACHIAL PLEXUS.

The brachial plexus (**plexus brachialis**) is a somewhat intricate interlacement of the anterior primary divisions of usually the lower four cervical and first thoracic nerves. To these are sometimes added a branch from the fourth cervical, a branch from the second thoracic, or branches from both of these nerves. The fasciculi form-

ing this plexus emerge in the interval between the scalenus anticus and medius and from the side of the neck pass beneath the clavicle and into the axilla through its apex. The plexus is divided, therefore, into two portions, a *cervical* or *supraclavicular* part (pars supraclavicularis) and an *axillary* or *infraclavicular* part (pars infraclavicularis). In the posterior cervical triangle the plexus lies first above and then to the outer side of the subclavian artery and vein, is crossed by the posterior belly of the omo-hyoid muscle and is frequently threaded by the transverse cervical or the posterior scapular artery. After entering the axilla its component parts, while lying mainly to the outer side, form a close fasces around the axillary artery, whose sheath they occupy. In the upper part of the axilla the plexus is overlain by the subclavius and pectoralis major muscles and before dividing into its terminal branches it lies enclosed between the pectoralis minor and subscapularis muscles.

Constitution and Plan.—In the various weavings of the component elements of the plexus five stages can be recognized: (*a*) anterior primary divisions of the spinal nerves, (*b*) trunks, (*c*) divisions, (*a*) cords and (*e*) terminal branches (Fig. 1091).

FIG. 1091.

Diagram illustrating plan of brachial plexus.

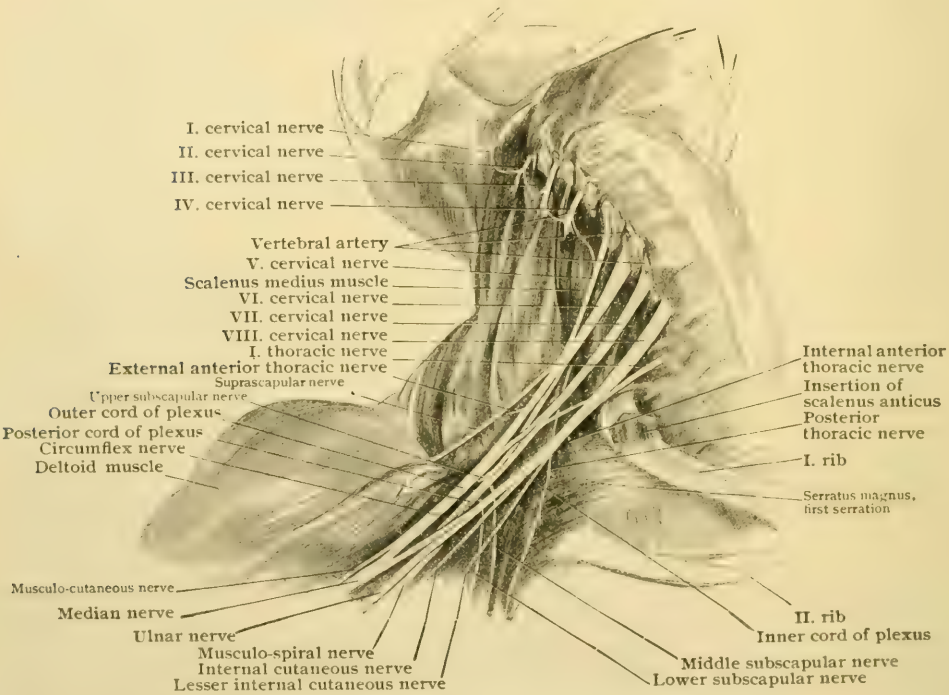
Emerging from the interval between the anterior and middle scalene muscles, the fifth and sixth cervical nerves unite to form the **outer** or **upper trunk**, the seventh alone is continued into the **middle trunk**, whilst the eighth cervical and first thoracic fuse to form the **inner** or **lower trunk**. These trunks continue undivided until slightly beyond the lateral margin of the scalenus anticus, each one then separating into an **anterior** and a **posterior division.** These are of about equal size, with the exception of the posterior division of the inner trunk, which is much smaller than the others because the first thoracic nerve sends few if any fibres to the posterior division. The six divisions, three anterior and three posterior, unite differently to form three cords. The **outer cord** (fasciculus lateralis) is the bundle formed by the union of the anterior divisions of the outer and middle trunks. The **posterior cord** (fasciculus posterior) is the result of the fusion of the posterior divisions of all of the trunks and the **inner cord** (fasciculus medialis) is the continuation of only the anterior division of the inner trunk. The trunks are named in correspondence with

their position as regards one another, while the cords are denominated according to their relation to the axillary artery, the outer lying lateral to, the inner mesial to, and the posterior behind, the artery.

Variations.—Considerable variety exists as regards the length of the component nerve-bundles in their several portions, division and union taking place at different levels in different individuals. The fifth cervical nerve may pass in front of or through the scalenus anticus. The sixth, though not so frequently as the fifth, may traverse the scalenus anticus. The seventh cervical nerve, as the middle trunk, may break up into three branches, one going to each of the three cords. The fibres of the posterior cord may arise from only the seventh and eighth, or the sixth, seventh and eighth cervical nerves. Plexuses have been seen in which only two cords, a smaller and a larger, were present, the latter taking the place of either the inner and outer or the inner and posterior cords.

Communications.—The five nerves comprising the source of the plexus are connected to the sympathetic system by gray rami communicantes and there is possibly a white ramus communicans passing from the first thoracic nerve to the first thoracic ganglion of the sympathetic.

FIG. 1092.



Deep dissection of neck, showing constitution of right brachial plexus.

Practical Considerations.—Sensory disturbances are rather rare in the distribution of the brachial plexus of nerves, but motor troubles are comparatively common, and are sometimes associated with disturbances of sensation. The whole plexus, or only an individual branch, may be involved. The most common cause is injury, such as dislocation of the head of the humerus, a fracture of the clavicle, or a forced apposition of the clavicle to the first rib. Other causes are the pressure of tumors or the constitutional effects of poisons and infections. The plexus is so superficial above the clavicle that it can be felt or even seen in thin people.

Branches.—These fall naturally into two groups, those given off from the *supraclavicular* and those from the *infraclavicular* portion of the plexus.

I. Supraclavicular Branches

1. Suprascapular
2. Posterior scapular
3. Posterior thoracic
4. Muscular
5. Communicating to the phrenic nerve

II. Infraclavicular Branches

A. *From Outer Cord:*
6. External anterior thoracic
7. Musculo-cutaneous
8. Median (outer head)

B. *From Inner Cord:*
9. Internal anterior thoracic
10. Lesser internal cutaneous
11. Internal cutaneous
12. Ulnar
13. Median (inner head)

C. *From Posterior Cord:*
14. Subscapular
15. Circumflex
16. Musculo-spiral

I. The Supraclavicular Branches.—These are given off at various levels while the plexus is still in the neck.

1. The **suprascapular nerve** (**n. suprascapularis**) (Fig. 1092) arises from the posterior surface of the outer trunk, most of its fibres coming from the fifth cervical nerve and the remainder from the sixth. It traverses the posterior cervical triangle above the upper border of the plexus and under cover of the omo-hyoid and trapezius muscles. Reaching the superior margin of the scapula, it passes through the suprascapular notch, under the suprascapular ligament, and enters the supraspinous fossa. After giving off a branch for the supply of the supraspinatus muscle and a tiny filament to the posterior portion of the capsular ligament of the shoulder, it passes through the great scapular notch in company with the suprascapular artery and vein. Having become an occupant of the infraspinous fossa, the nerve supplies the infraspinatus muscle and often gives off a branch to the shoulder joint.

Variations.—It may receive additional fibres from the fourth cervical nerve or may arise entirely from the fifth. A rare anomaly is the giving off of a branch to the teres minor or to the upper part of the subscapularis. Twigs to the scapula and its periosteum and to the acromioclavicular articulation have been described. Division into two parts may occur, the upper part passing through the notch and the lower through a bony foramen below the notch.

2. The **posterior scapular nerve** or **the branch to the rhomboid muscles** (**n. dorsalis scapulae**) (Fig. 1082) arises, in common with a root to the posterior thoracic nerve, from the dorsal aspect of the fifth cervical nerve. After traversing the substance of the scalenus medius, it passes downward and backward toward the vertebral border of the scapula, lying upon the deep surface of the levator anguli scapulæ and the rhomboidei. It supplies a filament to the levator anguli scapulæ and occasionally one to the upper digitation of the serratus posticus superior, and terminates by entering the substance of the rhomboideus major and minor muscles.

Variation.—It may pierce the levator anguli scapulæ.

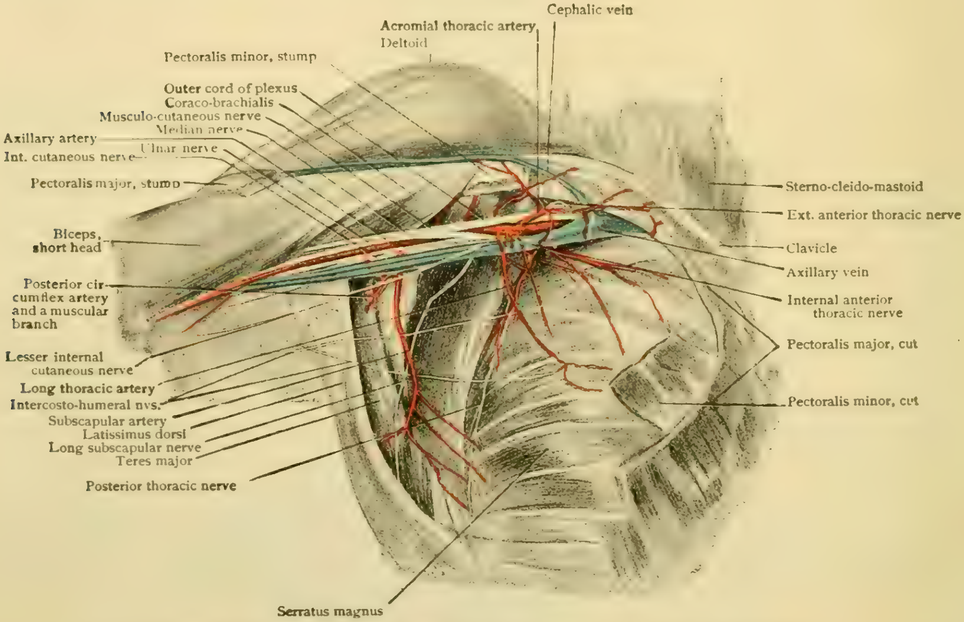
3. The **posterior thoracic** (**n. thoracalis longus**), also called the **long thoracic** or **external respiratory nerve of Bell** arises from the fifth, sixth and seventh cervical nerves, the largest contribution coming from the sixth (Fig. 1092). The roots from the fifth and sixth nerves pass through the scalenus medius and unite either in the substance of that muscle or as they reach its surface. The root from the seventh nerve passes anterior to the middle scalene muscle and unites with the main trunk at about the level of the first rib. Entering the axilla the nerve descends on

the inner wall, lying posterior to the brachial plexus and the axillary vessels, and upon the lateral aspect of the serratus magnus. It gives off successive twigs to the digitations of the last-named muscle, which alone it supplies. The fibres derived from the fifth cervical nerve supply the upper part, those from the sixth the middle and those from the seventh the lower part of the muscle.

Variations.—The contribution from the fifth nerve sometimes fails to join the main nerve and goes directly to its distribution to the upper digitations. The root from the seventh nerve may be absent. An additional root may be contributed by the eighth cervical nerve.

Practical Considerations.—The posterior thoracic nerve may be paralyzed by an injury in the suprascapular region or in the axilla, by carrying heavy weights upon the shoulder, or as a result of infectious disease, cold or rheumatism. The most noticeable sign is a prominence of the scapula (winged scapula), from the failure of the paralyzed serratus magnus muscle to hold the vertebral border of the scapula close to the thorax. That border and the inferior angle project and

FIG. 1093.



Dissection of right axilla, showing relations of brachial plexus to blood-vessels.

become prominent. When the arm is in front of the chest the deformity is most marked and the lower angle approaches the mid-line of the back. The patient cannot lift anything heavy with the affected arm. Since the incision to open an axillary abscess is made vertically in the middle of the thoracic wall of the axillary space, to avoid the vessels at its borders, this nerve is in some danger as it passes to the serratus magnus muscle.

4. The **muscular branches** supply the longus colli, the scaleni anticus, medius and posticus and the subclavius.

a. The **longus colli** and **scalenus anticus** are supplied by small twigs which arise from the anterior surface of the lower four cervical nerves as they leave the vertebral column.

b. The **scaleni medius** and **posticus** receive fibres given off from the posterior aspect of the lower four cervical nerves as they pass through the intervertebral foramina.

c. The **nerve to the subclavius** (**n. subclavius**) takes its origin from the outer trunk of the plexus, its fibres coming mainly from the fifth cervical nerve. It passes through the subclavian triangle, over the third portion of the subclavian artery and behind the clavicle, to enter the deep surface of the subclavius muscle.

Variations.—The phrenic nerve may give off a branch to the subclavius or may receive a filament from the nerve to the subclavius. A branch of communication with the external anterior thoracic and a branch to the clavicular head of the sterno-cleido-mastoid have been noted.

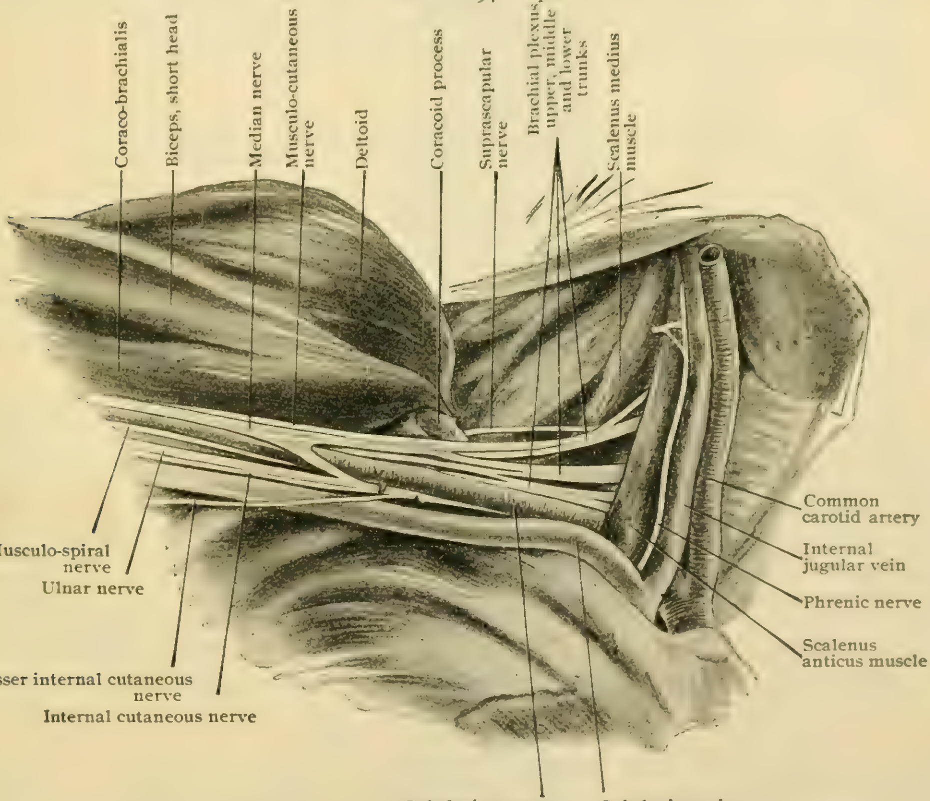
5. The **communicating branch to the phrenic nerve** (Fig. 1090) arises usually from the fifth cervical nerve, sometimes from the fifth and sixth. Originating at the outer margin of the scalenus anticus it passes inward and joins the phrenic. If this nerve is not present the nerve to the subclavius usually supplies the deficiency.

II. The Infraclavicular Branches.—These branches comprise those given off by the three cords of the plexus after the latter has passed beneath the clavicle into the axilla.

6. The External Anterior Thoracic Nerve.

The external anterior thoracic nerve (**n. thoracalis anterior lateralis**) (Fig. 1093) receives its fibres from the fifth, sixth and seventh cervical nerves. Leaving the outer cord beneath the clavicle, it passes mesially over the axillary artery and, after giving

Fig. 1094.



Dissection of right axilla, showing relation of brachial plexus to subclavian and axillary vessels with arm abducted.

off a filament which unites with a similar structure from the internal anterior thoracic nerve, divides into two branches which pierce the costo-coracoid membrane and enter the deep surface of the pectoralis major. The upper branch supplies the clavicular portion of the muscle and the lower branch the upper part of the sternal portion.

The loop between the anterior thoracic nerves gives off a filament which pierces the pectoralis minor and ends in the sternal part of the pectoralis major, to both of which muscles it is distributed.

Variations.—This nerve may supply fibres to the clavicular portion of the deltoid and to the acromio-clavicular articulation.

7. The Musculo-Cutaneous Nerve.

The musculo-cutaneous nerve (**n. musculocutaneus**) (Fig. 1098) derives its fibres from the fifth and sixth, and sometimes the seventh, cervical nerves and is a branch of the outer cord. The *nerve to the coraco-brachialis muscle*, derived from the seventh or sixth and seventh nerves, is usually found as an integral part of it. Leaving the outer cord under cover of the pectoralis minor it pierces the coraco-brachialis and passes obliquely downward and outward between the biceps and brachialis anticus muscles. Reaching the outer margin of the biceps a short distance above the elbow, the nerve pierces the deep fascia and passes under the median-cephalic vein. It then becomes superficial (**n. cutaneus antebrachii lateralis**) and divides into its terminal cutaneous branches.

Branches.—These are: (*a*) the *muscular*, (*b*) the *humeral*, (*c*) the *articular* and (*d*) the *terminal*.

a. The **muscular branches** supply the coraco-brachialis, the biceps and the brachialis anticus. The *nerve to the coraco-brachialis*, which commonly has an independent origin, is usually double, one filament going to each portion of the muscle. The nerves to the *biceps* and *brachialis anticus* are given off while the musculo-cutaneous is in transit between those muscles.

b. The **humeral branch** accompanies the nutrient branch of the brachial artery into the humerus.

c. The **articular branch** aids in the supply of the elbow joint.

d. The **terminal part** (**n. cutaneus antebrachii lateralis**) (Fig. 1103) of the musculo-cutaneous divides into two branches, (*aa*) an *anterior* and (*bb*) a *posterior*.

aa. The *anterior branch* descends in the antero-lateral portion of the superficial fascia of the forearm (Fig. 1104). It inosculates above the wrist with the radial nerve and supplies the integument of the antero-lateral part of the forearm. It also distributes fibres to the skin over the thenar eminence, to the wrist joint and to the radial artery.

bb. The *posterior branch* passes downward and backward and supplies the skin of the postero-lateral portion of the forearm down to or slightly beyond the wrist joint (Fig. 1102). It inosculates with the radial nerve and with the inferior external cutaneous branch of the musculo-spiral.

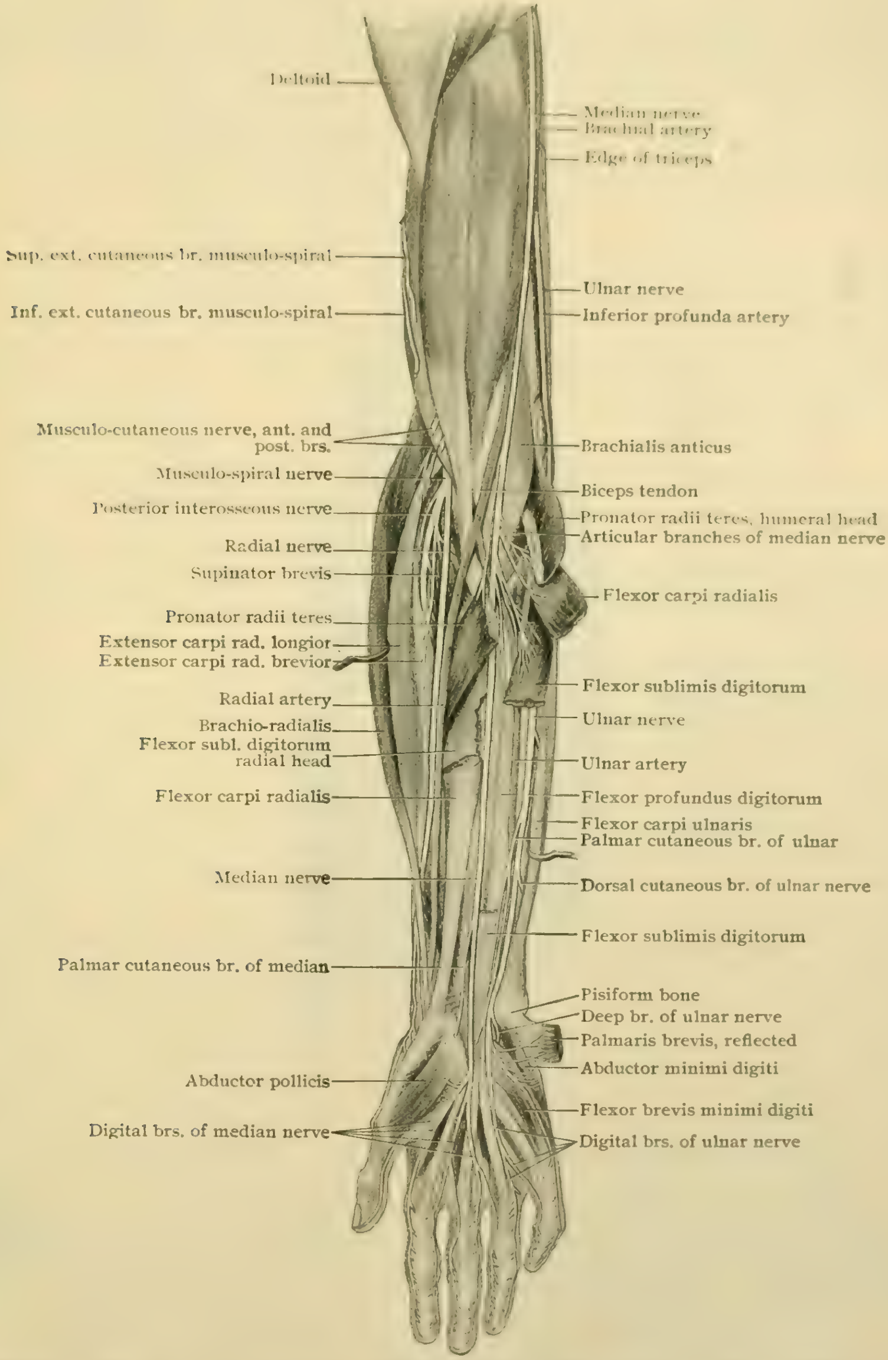
Variations.—Instead of piercing the coraco-brachialis the nerve may adhere to the median or its outer head for some distance down the arm, and then either as a single trunk or as several branches pass between the biceps and brachialis anticus muscles. Sometimes only a part of the nerve follows this course, joining the main trunk after the latter's transit through the muscle. The muscular part only or the cutaneous part only may pierce the muscle. The nerve may be accompanied through the muscle by fibres of the median which rejoin the latter below the coraco-brachialis. The nerve may remain independent and fail to pierce the coraco-brachialis, either passing behind it or between it and the associated head of the biceps. It may perforate not only the coraco-brachialis but also the brachialis anticus or the short head of the biceps. Rarely the entire outer cord, after giving off the external anterior thoracic, may traverse the coraco-brachialis. Anomalies in distribution include a branch to the pronator radii teres, the supply of the skin of the dorsum of the hand over and adjacent to the first metacarpal bone, a branch to the dorsum of the thumb in the absence of the radial nerve and the giving off of dorsal digital nerves to both sides of the ring finger and the adjacent side of the little finger.

8. The Median Nerve.

The median nerve (**n. medianus**) (Fig. 1098) consists of fibres which can be traced to the sixth, seventh and eighth cervical and first thoracic nerves. It arises by two heads, an outer and an inner, which are derived respectively from the outer and inner cords of the plexus, the former containing fibres from the sixth and seventh cervical and the latter fibres from the eighth cervical and first thoracic nerves. The two heads, the inner of which usually crosses the main artery of the upper extremity at about the point where the axillary becomes brachial, unite either in front of or to the outer side of the artery. From the point of fusion of the two heads the nerve passes down the arm in close relation with the brachial artery, usually lying lateral or antero-lateral to the artery in the upper part of the arm, and as the elbow is neared, gradually attaining the inner side by crossing obliquely the anterior surface of the artery (Fig. 1098). It passes through the cubital fossa beneath the median-basilic vein and the bicipital fascia, and enters the forearm between the heads of the pronator radii teres muscle, the deep head of

which separates the nerve from the ulnar artery. It follows a straight course down the forearm, accompanied by the median artery, lying upon the flexor profundus

FIG. 1095.



Dissection of right upper extremity, showing nerves of anterior surface; anterior annular ligament has been cut away to show median nerve and flexor tendons.

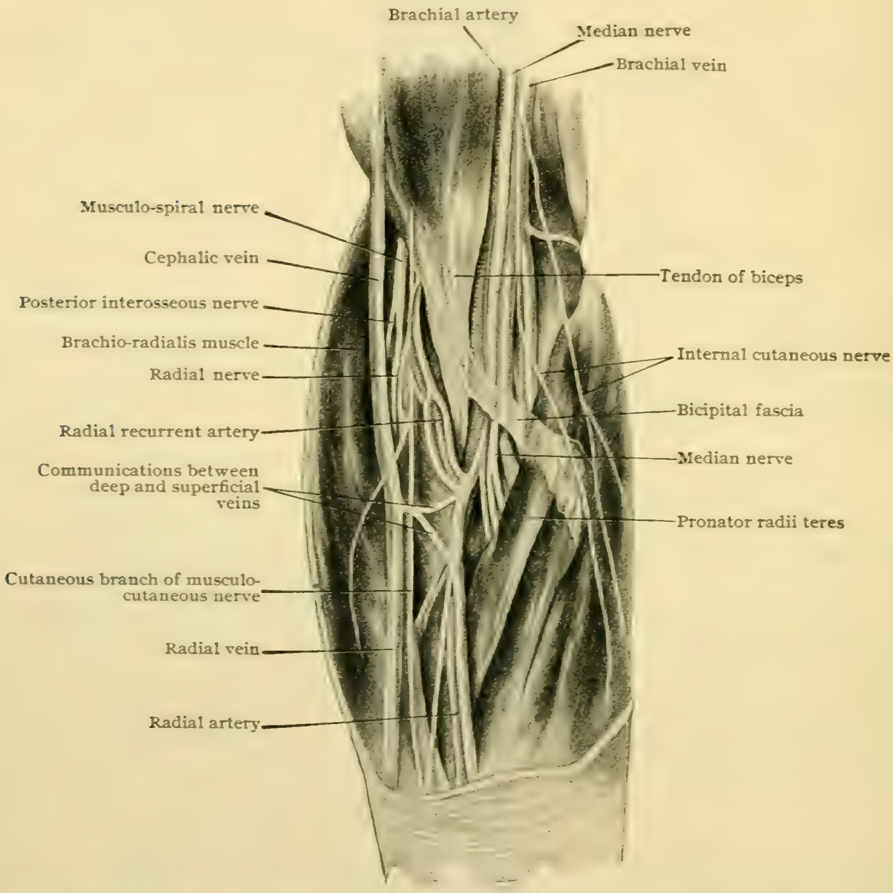
digitorum and covered by the flexor sublimis digitorum. Near the wrist the median becomes more superficial, with the tendons of the flexor sublimis digitorum

and palmaris longus lying mesial and that of the flexor carpi radialis lateral to it (Fig. 1095). It passes into the hand beneath the anterior annular ligament, at the lower margin of which it spreads out into a reddish gangliform swelling, which lies upon the flexor tendons. Below this point it breaks up into its terminal branches.

Branches.—The median, as is the case with the ulnar, gives off no branches in the arm. In the forearm the branches are : (*a*) the *articular*, (*b*) the *muscular*, (*c*) the *anterior interosseous* and (*d*) the *palmar cutaneous*, and in the hand : (*e*) the *muscular* and (*f*) the *digital*.

a. The **articular branch** consists of one or two tiny twigs which supply the anterior portion of the elbow joint.

FIG. 1096.



Superficial dissection of right arm, showing relations of nerves to blood-vessels on front of elbow.

b. The **muscular branches** (rr. musculares) (Fig. 1095) consist of a fasces of nerve-bundles which arise from the median a short distance below the elbow. They are distributed to the pronator radii teres, the flexor carpi radialis, the palmaris longus and that portion of the flexor sublimis digitorum which arises from the inner condyle and from the ulna. Two additional filaments from the median supply the flexor sublimis, one entering the radial head and the other that portion which flexes the index finger.

c. The **anterior interosseous nerve** (n. interosseus antebrachii volaris) (Fig. 1098) arises from the posterior aspect of the median a short distance below the elbow. It passes down the forearm, accompanied by the anterior interosseous artery, on the anterior surface of the interosseous membrane between the flexor longus pollicis and the flexor profundus digitorum. At the upper margin of the pronator quadratus muscle it dips under that muscle and continues down for some distance, finally entering the deep surface of the pronator quadratus.

It supplies the flexor longus pollicis, the radial half of the flexor profundus digitorum and the pronator quadratus. It distributes filaments to the interosseous membrane, the anterior interosseous vessels, the shafts of the radius and ulna (the twigs to these bones entering them with the nutrient arteries), the periosteum of the radius and ulna and the radio-carpal articulation.

d. The **palmar cutaneous branch** (**r. cutaneus palmaris**) (Fig. 1097) leaves the median at a varying distance above the wrist. It becomes superficial near the upper margin of the anterior annular ligament by piercing the deep fascia between the flexor carpi radialis and the palmaris longus. It supplies the skin of the palm and inosculates with the palmar cutaneous branch of the ulnar and with filaments of the radial and musculo-cutaneous nerves.

e. The **muscular branch in the hand** (**r. muscularis**) (Fig. 1097) is a short nerve which arises below the anterior annular ligament and curves outward toward the base of the thumb. It breaks up into filaments which supply the abductor pollicis, the opponens pollicis and the superficial head of the flexor brevis pollicis.

f. The **digital branches** (Fig. 1097) are five in number and, with the exception of the twigs supplying the two outer lumbricales, are purely sensory. They arise from the median a short distance below the anterior annular ligament of the wrist (**nn. digitales volares communes**) and pass distally beneath the superficial palmar arch and over the flexor tendons. As they approach the interdigital clefts they pass between the primary divisions of the median portion of the palmar fascia and become more superficial as they continue along the borders of the fingers (**nn. digitales volares proprii**).

The **first** lies along the radial side of the thumb and inosculates around its radial aspect with the radial nerve.

The **second** occupies the ulnar side of the thumb.

The **third** gives off a branch to the first lumbricalis and supplies the radial side of the index finger.

The **fourth** supplies the second lumbricalis and then divides into two branches which are distributed to the adjacent sides of the index and middle fingers.

The **fifth**, after being connected with the ulnar nerve by a stout filament (**r. anastomoticus cum n. ulnare**), divides for the supply of the adjoining aspects of the middle and ring fingers.

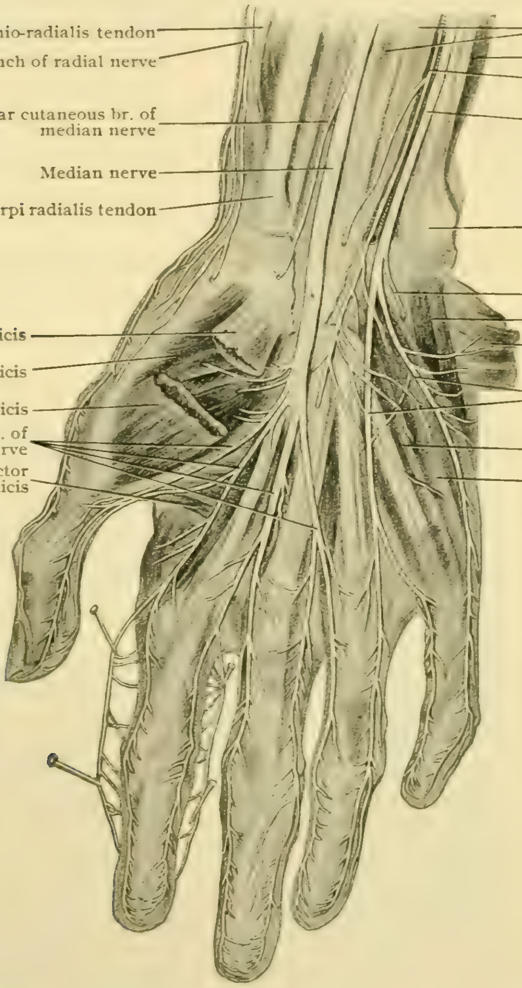
In the fingers these nerves lie anterior to the vessels and in their course toward the tip of the finger they give off anterior and posterior branches, the latter supplying the skin over the middle and distal phalanges of the index, middle and ring fingers and over the distal phalanx of the thumb. Twigs are supplied to the interphalangeal articulations and near the end of the finger each of the five breaks up into two terminal branches, one of which is destined for the sensitive skin over the anterior portion of the distal phalanx and the other for the matrix of the nail.

Variations.—Some of these are described on page 1298. The fibres usually contributed to the median nerve by the first thoracic may be wanting. Either the outer or the inner head may consist of two nerve-bundles. The point at which the heads unite is a very variable one and has been found as far down as the elbow. The heads may enclose the axillary vein instead of the artery. In those instances, many of which have been found in the anatomical rooms of the University of Pennsylvania, in which a single large branch of the axillary artery gives off the two circumflex arteries, the subscapular and the two profunda arteries, this trunk, instead of the axillary artery, is embraced by the heads of the median nerve. The inner head, the outer head or the median itself may pass behind the axillary artery instead of in front. The outer head has been seen to arise in the middle of the arm and pass behind the artery to join the inner head. One instance has been reported in which the median entered the forearm over the pronator radii teres instead of between the heads of that muscle. It has been seen lying on the superficial surface of the flexor sublimis digitorum. The median may be cleft for a short distance in the forearm, giving passage to the ulnar artery or one of its branches, to the superficial long head of the flexor longus pollicis or to an extra palmaris longus muscle. A communication in the arm between the median and ulnar nerves has been noted in one instance. A similar connection in the forearm, occurring in numerous ways, is found in from 20–25 per cent. of cases examined. A connection with the ulnar in the hand may pass either from the ulnar to the median or from the median to the ulnar. The anterior interosseous has been seen to receive a filament from the musculo-spiral through the interosseous membrane, and inosculation between the two interosseous nerves has been noted at the lower part of the forearm; according to Rauber, this is the normal arrangement. One case has been described in which the abductor indicis was supplied by the median. During the exchange of position between the digital branches of the median nerve and the digital arteries the former are often pierced by the latter. The fifth digital branch may arise in the forearm and enter the hand independently.

Practical Considerations.—A pure paralysis of the median nerve is rare, and is almost always traumatic in origin. The paralysis is more commonly a part of a more extended involvement of the brachial plexus. When this nerve is paralyzed above there is inability to pronate the forearm or flex the wrist properly, since the

pronators and all the flexors except the flexor carpi ulnaris and the ulnar half of the flexor profundus digitorum are supplied by it. The second phalanges of the middle and index fingers cannot be flexed, although the first phalanges can be flexed and the second and third extended in all the fingers through the interossei muscles; flexion of the third phalanges of the little and ring fingers can be accomplished by the ulnar half of the flexor profundus, which is supplied by the ulnar nerve. The

FIG. 1097.



Superficial dissection of right palm, showing branches of median and ulnar nerves; part of anterior annular ligament has been removed to expose median nerve.

thumb cannot be flexed or abducted, although it may be adducted. One of the most characteristic features of the hand is lost—that is, the ability to appose the thumb to any one of the fingers, as in picking up small objects.

In wounds of the axilla the median is the nerve most frequently injured, the musculo-spiral least frequently, as the median lies more superficially and the musculo-spiral behind the vessels. In the arm the median can be easily found to the inner side of the biceps and coraco-brachialis muscles, where it lies on the brachial vessels. At the elbow it is found to the inner side of the brachial artery, the guide to which is the biceps tendon which in turn lies just to the outer side of the artery. At about the middle of the wrist the nerve lies under the palmaris longus tendon.

9. The Internal Anterior Thoracic Nerve.

The internal anterior thoracic nerve (**n. thoracalis anterior medialis**) (Fig. 1093) arises from the inner cord and consists of fibres derived from the eighth cervical and first thoracic nerves. It passes forward between the axillary artery and vein and, after giving off a branch which forms a loop with a similar branch from the external anterior thoracic, pierces the pectoralis minor, in which some of its fibres terminate. The remainder enter the deep surface of the pectoralis major to supply the lower part of the sternal portion of that muscle.

Variations.—The fibres which supply the pectoralis major may wind around the lower border of the pectoralis minor. Filaments from both of the anterior thoracic nerves may supply the integument of the axillary and mammary regions.

10. The Lesser Internal Cutaneous Nerve.

The lesser internal cutaneous nerve (**n. cutaneus brachii medialis**) (Fig. 1093), also called the *nerve of Wrisberg*, can be traced to the first thoracic nerve. It arises from the inner cord usually in common with the internal cutaneous. After leaving its point of origin, it descends in the arm along the inner side of the axillary and basilic veins, pierces the deep fascia about the middle of the arm and supplies the integument of the inner aspect of the upper extremity as far down as the elbow. At a variable point it forms a loop with the intercosto-humeral nerve.

Variations.—The lesser internal cutaneous nerve may be absent. It may receive fibres from the eighth cervical or the second thoracic nerve. There may be present a communication between the lesser internal cutaneous nerve and the lateral cutaneous branch of the third thoracic. The inosculation with the intercosto-humeral may be either simple or plexiform and either nerve may be deficient, the other usually recompensing for the deficiency.

11. The Internal Cutaneous Nerve.

The internal cutaneous nerve (**n. cutaneus antebrachii medialis**) (Fig. 1094) comprises fibres from the eighth cervical and first thoracic nerves. It has its origin from the inner cord of the plexus usually as a common trunk with the lesser internal cutaneous nerve. After distributing some small filaments to the integument of the upper arm below the axilla, it runs down the arm between the brachial artery and the basilic vein and at about the middle of the upper arm breaks up into its terminal branches, (*a*) the *anterior* and (*b*) the *posterior*.

a. The **anterior branch** (**r. volaris**) passes over, sometimes under, the median-basilic vein and supplies the skin of the ulnar half of the forearm as far down as the wrist (Fig. 1104). It inosculates with the superficial branch of the ulnar nerve.

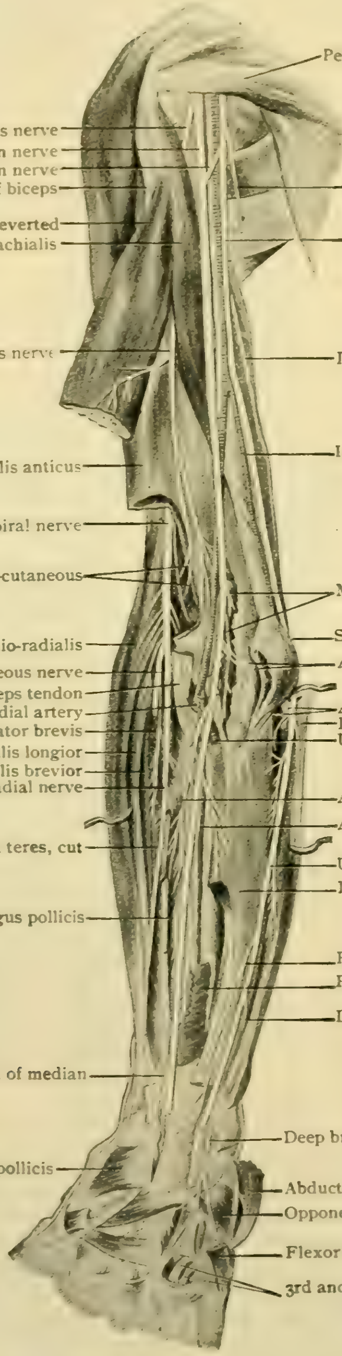
b. The **posterior branch** (**r. ulnaris**) turns obliquely around the inner side of the upper part of the forearm and supplies the integument as far around as the ulna down to the lower third or fourth of the forearm. It unites above the elbow with the lesser internal cutaneous nerve and in the forearm with the anterior branch of the internal cutaneous and sometimes with the dorsal ramus of the ulnar.

12. The Ulnar Nerve.

The ulnar nerve (**n. ulnaris**) (Fig. 1092) is the largest branch of the inner cord. Its fibres can be traced to the eighth cervical and first thoracic nerves and sometimes, by a root from the outer cord, to the seventh cervical. Arising from the inner cord between the axillary artery and vein and posterior to the internal cutaneous nerve it pursues a downward course in front of the triceps and to the inner side of the axillary and brachial arteries. Reaching the middle of the arm it follows an inward and backward direction, in which it is accompanied by the inferior profunda artery, and passing either over the inner margin of or through the internal intermuscular septum and in front of the inner head of the triceps, attains the interval between the internal condyle of the humerus and the olecranon (Fig. 1098). It becomes an occupant of the forearm by passing between the heads of the flexor carpi ulnaris muscle, a situation the nerve shares with the inferior profunda and posterior

ulnar recurrent arteries. From this point the nerve follows a straight course to the wrist, lying in the forearm upon the flexor profundus digitorum and covered by the

FIG. 1098.



Dissection of right upper extremity, showing deeper branches of nerves of anterior surface.

flexor carpi ulnaris. At about the middle of its course through the lower arm it approximates the ulnar vessels, close to the inner side of which it lies. At the

wrist, accompanied by the ulnar artery, it pierces the deep fascia just above the annular ligament, to the outer side of the pisiform bone, and enters the hand by passing superficial to the anterior annular ligament (Fig. 1097). After crossing the ligament it divides into its terminal branches, the *superficial* and the *deep*.

Branches.—None are given off in the arm. **In the forearm** they are: (*a*) the *articular*, (*b*) the *muscular*, (*c*) the *cutaneous* and (*d*) the *dorsal branch to the hand*. The terminal branches **in the hand** are: (*e*) the *superficial* and (*f*) the *deep*.

a. The **articular branch** consists of one or two filaments which leave the ulnar as it lies in the interval between the olecranon and the internal condyle. They pierce the internal part of the capsular ligament and supply the elbow joint.

b. The **muscular branches** arise from the ulnar in the immediate neighborhood of the elbow and supply the flexor carpi ulnaris in toto and the ulnar half of the flexor profundus digitorum. They consist of several fine twigs which leave the ulnar nerve as it lies between the heads of the flexor carpi ulnaris.

c. The **cutaneous branches** are two small filaments which arise by a common trunk at about the middle of the forearm. One, which is inconstant, after piercing the deep fascia, runs downward to inosculate with a twig from the internal cutaneous. The other, the **palmar cutaneous branch** (**r. cutaneus palmaris**) (Fig. 1097), lies superficial to the ulnar artery, which it accompanies to the hand almost as far as the superficial palmar arch. It sends filaments to the ulnar artery and breaks up into a number of tiny threads which supply the integument of the hypothenar region and inosculate with other cutaneous twigs of the ulnar, with the internal cutaneous and with the palmar cutaneous branch of the median.

d. The **dorsal branch to the hand** (**r. dorsalis manus**) is a good sized trunk which leaves the ulnar in the upper part of the lower half of the forearm. To reach the dorsum of the hand it passes downward and backward between the tendinous portion of the flexor carpi ulnaris and the shaft of the ulna, giving off a branch over the dorsum of the wrist to supply that region and inosculate with a twig from the radial nerve. Opposite the head of the ulna it splits into three branches (**nn. digitales dorsales**) for the supply of the fingers. The **ulnar or inner branch** courses along the inner side of the little finger to ramify in its integument as far as the base of the nail. The **middle branch** follows the fourth metatarsal interval and divides into two filaments, one extending along the radial side of the little finger as far as the base of the nail and the other along the ulnar side of the ring finger as far as the proximal side of the ungual phalanx. The **radial or outer branch** passes toward the base of the space between the ring and middle fingers and inosculates with the branch from the radial nerve for the same cleft. It divides into two sub-branches and in connection with the radial supplies the adjacent sides of the ring and middle fingers (Fig. 1102). At the lateral aspect of the fingers all of these branches inosculate with the palmar digital cutaneous nerves.

e. The **superficial terminal branch** (**r. superficialis n. ulnaris**) (Fig. 1097) furnishes small twigs to the palmaris brevis muscle, to the integument of the ball of the little finger and sometimes to the fourth lumbricalis. It then divides, one of its subdivisions supplying the ulnar side of the little finger while the other breaks up into two portions which course along the adjoining sides of the little and ring fingers. The ultimate distribution of these filaments is similar to that of the digital branches of the median nerve (page 1301).

A twig of communication passes between the branch for the little and ring fingers and that from the median for the ring and middle fingers. From the latter tiny threads are supplied to the integument and vessels of the palm.

f. The **deep terminal branch** (**r. profundus n. ulnaris**) (Fig. 1099) accompanies the deep branch of the ulnar artery and sinks deeply into the palm between the abductor and flexor minimi digiti muscles. It passes internal to and below the uncus of the unciform bone, in which a groove for the nerve is sometimes found, crosses the palm with the deep palmar arch under the deep flexor tendons and breaks up into terminal twigs on its arrival at the adductor transversus pollicis (Fig. 1199). **Muscular branches** (**rr. musculares**) are furnished to the abductor, opponens and flexor minimi digiti, the third and fourth lumbricales, the palmar and dorsal interossei, the adductores obliquus and transversus pollicis and the deep head of the flexor brevis pollicis. **Articular branches** are supplied to the intercarpal and metacarpo-phalangeal articulations and tiny **perforating branches** accompany the posterior perforating arteries between the heads of the second, third and fourth dorsal interosseous muscles and inosculate with the terminal twigs of the posterior interosseous nerve (Rauber).

Communications.—The ulnar communicates freely and in many different situations with the median and this close interlacing is paralleled by their similarity in distribution. Both give off no branches above the elbow, both supply the elbow joint, between them they supply all the muscles of the flexor surface of the forearm, both send filaments to the wrist joint and the integument of the palm and between them all the muscles of the hand, the palmar aspect of all the digits and the interphalangeal articulations are innervated.

Further description of the communications of the ulnar nerve, in addition to those just mentioned, will be found in connection with the median nerve (page 1301).

Variations.—The ulnar may have a root from the seventh cervical nerve by way of the outer cord, or may be derived from the eighth cervical only or from the seventh and eighth. It may pass in front of the internal condyle or lie behind the condyle and slip forward during flexion of the elbow. Connecting twigs have been seen passing from the ulnar to the internal cutaneous, to the median in the upper arm and to the musculo-spiral. Frequently there is an associating branch in the forearm between the median and the ulnar. Muscular twigs have been noted as passing to the inner head of the triceps, the flexor sublimis digitorum, the first and second lumbricales and the superficial head of the flexor brevis pollicis. Deficiencies in the branch to the dorsum of the hand have been observed to be compensated for by the radial, the inferior external cutaneous branch of the musculo-spiral or the internal cutaneous. In a specimen with absence of the radial nerve all four fingers were supplied by the ulnar. The dorsal terminal filaments of the ulnar tend to encroach on the radial side of the hand and in one case reached the dorsum of the first phalanx of the thumb.

Practical Considerations.—In paralysis of the ulnar nerve, flexion of the wrist is impaired, and also (on account of the flexor carpi ulnaris paralysis) lateral motion toward the ulnar side (adduction). There is difficulty in spreading the fingers, as all the interossei are supplied by this nerve. The hand will be "clawed" from the paralysis of the interossei, which now fail to resist the action of the extensors on the proximal phalanges, and of the flexors on the distal and medial, except in the middle and ring fingers where the flexor profundus—its ulnar half being paralyzed—has only a slight influence on the distal phalanges. Besides the flexor carpi ulnaris, the ulnar half of the flexor profundus and the interossei, the ulnar nerve supplies all the hypothenar muscles, the adductor pollicis, the inner half of the flexor brevis pollicis and the two ulnar lumbricales ; consequently the hypothenar eminence disappears and the thenar eminence shows atrophy in ulnar paralysis. This nerve is involved particularly in those whose occupations require them to press their elbows against hard objects or to strike blows frequently with the ulnar border of the hand. It may be injured in fractures of the elbow, particularly of the internal condyle. In the forearm and wrist it is the nerve most frequently injured. It is found on the inner side of the brachial artery in the upper half of the arm, but in the lower half it passes posteriorly to the bony interval between the internal condyle and the olecranon, where it is readily located by pressure, which causes a tingling sensation down the forearm. The same sensation is often produced by blows on the elbow, the nerve being compressed between the internal condyle and the olecranon. It is the structure most frequently damaged in excisions of the elbow. In the lower two-thirds of the forearm it lies to the radial side of the flexor carpi ulnaris muscle and to the ulnar side of the ulnar artery. At the wrist it passes over the anterior annular ligament in the same relation to the artery and to the radial side of the pisiform bone.

14. The Subscapular Nerves.

The subscapular nerves (**nn. subscapulares**) (Fig. 1092) arise from the posterior cord and are usually three in number. Together they supply the three muscles which form the posterior boundary of the axillary space.

The **upper** or **short subscapular nerve** is composed of fibres which are prolonged from the fifth and sixth cervical nerves. It often is either double in origin or divides into two branches shortly after leaving the posterior cord. It arises behind the circumflex nerve and after a short course enters the inner surface of the subscapularis near the upper margin of that muscle.

The **middle** or **long subscapular nerve** (**n. thoracodorsalis**), the largest of the three, arises from the rear aspect of the posterior cord, behind the origin of the musculo-spiral nerve. Its fibres are derived from the sixth, seventh and eighth cervical nerves, the majority of them coming from the seventh. It takes a course downward and outward on the posterior axillary wall behind the axillary artery, and accompanies the subscapular artery to the deep surface of the latissimus dorsi, before entering which it breaks up into a number of strands.

The **lower subscapular nerve** obtains its fibres from the fifth and sixth cervical nerves. It arises from the posterior cord behind the origin of the circumflex

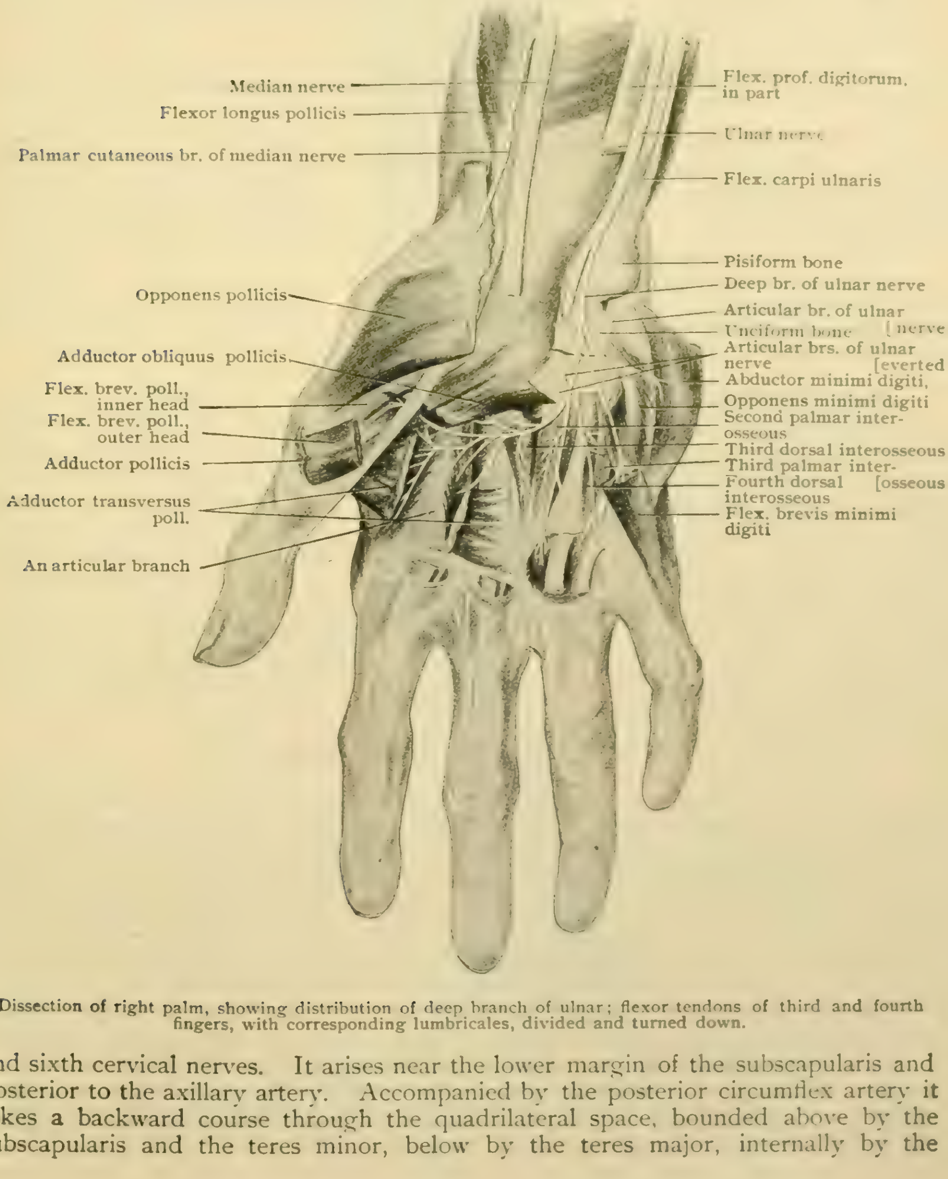
and passes downward and outward beneath the axillary artery and the circumflex and musculo-spiral nerves. It sends fibres to the inferior portion of the subscapularis muscle and terminates in the substance of the teres major.

Variations. As regards origin the upper may arise from either the fifth or the sixth cervical nerve, the middle from the seventh alone or from the seventh and eighth or rarely by an additional filament from the fifth, and the lower from the fifth, sixth and seventh or from the fifth or sixth alone. As regards distribution, the nerves to the lower part of the subscapularis and to the teres major may proceed separately from the brachial plexus or the latter nerve may be a branch of the circumflex.

15. The Circumflex Nerve.

The circumflex or axillary nerve (**n. axillaris**) (Fig. 1092) is one of the terminal branches of the posterior cord and contains fibres which are derivatives of the fifth

Fig. 1099.



Dissection of right palm, showing distribution of deep branch of ulnar; flexor tendons of third and fourth fingers, with corresponding lumbricales, divided and turned down.

and sixth cervical nerves. It arises near the lower margin of the subscapularis and posterior to the axillary artery. Accompanied by the posterior circumflex artery it takes a backward course through the quadrilateral space, bounded above by the subscapularis and the teres minor, below by the teres major, internally by the

humeral head of the triceps and externally by the humerus. Having traversed this space it winds around the surgical neck of the humerus and reaches the outer aspect of the shoulder.

Branches.—These are : (*a*) the *articular*, (*b*) the *cutaneous* and (*c*) the *muscular*.

a. The **articular branches** are usually two in number. The upper arises near the origin of the circumflex and the lower during the passage of the nerve through the quadrilateral space. They supply the anterior inferior portion of the capsular ligament of the shoulder. A third articular branch is described as passing up the bicipital groove, supplying a twig to the upper end of the humerus and one to the neighboring portion of the capsular ligament of the shoulder.

b. The **cutaneous branch** (**n. cutaneus brachii lateralis**) arises as a common trunk with the nerve to the teres minor. It becomes superficial between the long head of the triceps and the posterior border of the lower third of the deltoid and is distributed to the integument over the posterior half of the deltoid and the posterior surface of the upper half of the arm.

One or two cutaneous filaments are derived from the muscular branches to the deltoid. They pierce the deltoid and are distributed to the skin over the lower portion of that muscle.

c. The **muscular branches** (**rr. musculares**) innervate (*aa*) the teres minor and (*bb*) the deltoid.

aa. The **nerve to the teres minor** arises from the circumflex at the posterior margin of the quadrilateral space and enters the middle of the posterior inferior border of the muscle which it supplies.

bb. The **deltoid branches** comprise the largest portion of the nerve and consist of its terminal fibres. The terminal portion of the circumflex forms a bow, with its convexity in contact with the deep surface of the deltoid, extending around the upper part of the humerus almost as far forward as the anterior margin of the deltoid muscle. It gradually diminishes in size as the result of the departure of a series of twigs which enter and supply the fasciculi of the deltoid.

Variations.—The circumflex may receive very few or no fibres from the sixth cervical nerve. It may pierce the subscapularis and may supply that muscle. It may give origin to the nerve to the teres major and has been observed to furnish filaments to the long head of the triceps and to the infraspinatus.

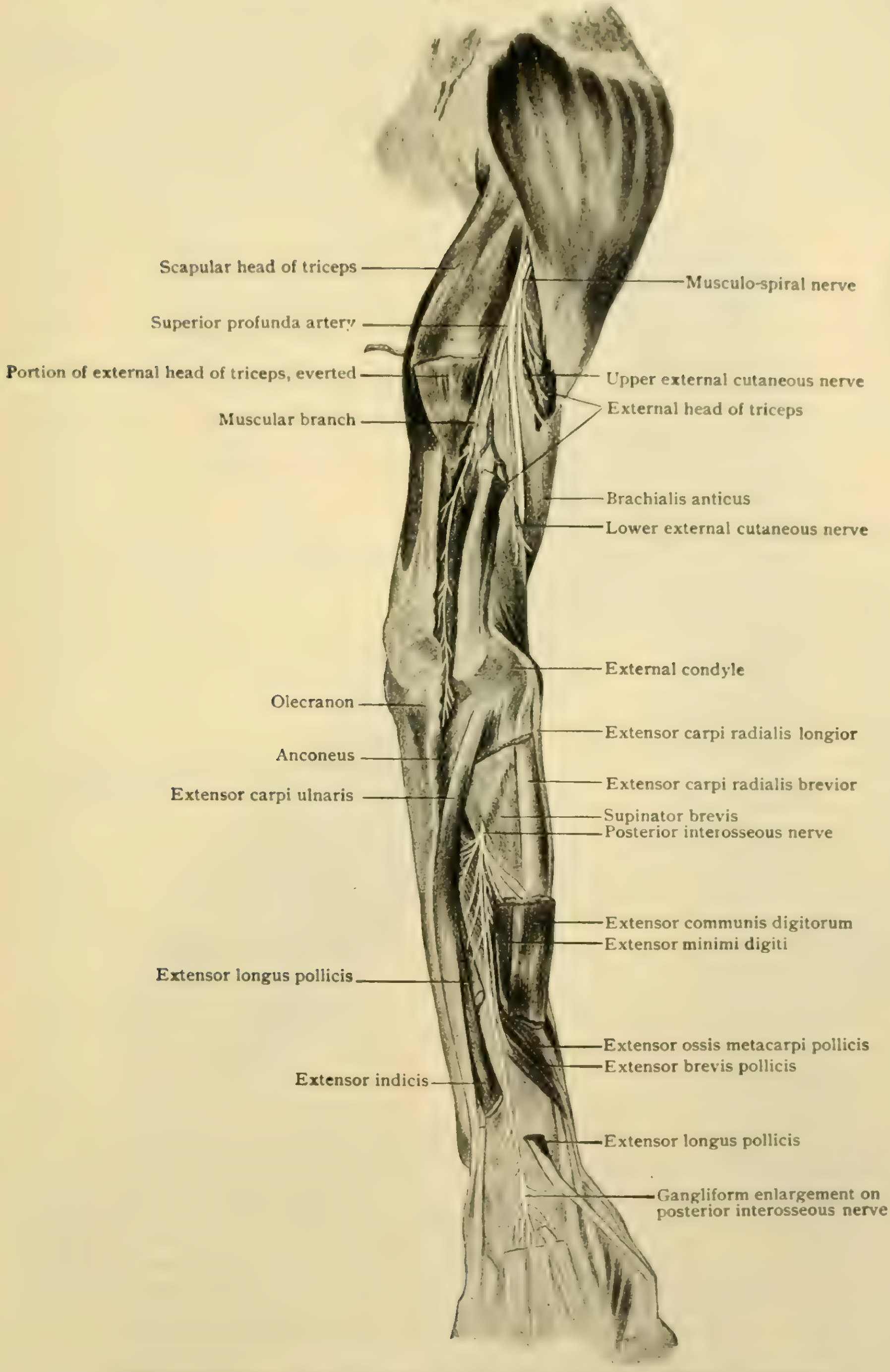
Practical Considerations.—The circumflex nerve is frequently paralyzed from injuries to the shoulder, as in birth palsies when pressure is made in the axilla. It undergoes special strain in dislocations of the shoulder, the nerve being stretched over the head of the humerus and often lacerated. Other branches of the brachial plexus may be injured in this dislocation. Since the circumflex passes around the humerus at about the level of the surgical neck it is sometimes damaged in fractures in that situation. The most prominent symptom in paralysis of this nerve is loss of the rotundity of the shoulder from atrophy of the deltoid muscle. As the circumflex winds around the posterior surface of the humerus and reaches the anterior part of the deltoid muscle from behind, incisions for reaching the shoulder joint, as in excisions, should be made anteriorly, since only the terminal branches of the circumflex will then be divided ; paralysis of the deltoid is thus prevented.

16. The Musculo-Spiral Nerve.

The musculo-spiral nerve (**n. radialis**) (Fig. 1100), the larger terminal branch of the posterior cord, is in fact the continuation of the latter. Its component fibres are derivatives of the sixth, seventh and eighth, and sometimes of the fifth, cervical nerves and it is distributed to the muscles and integument of the extensor surface of the arm, forearm and hand. After separating from the circumflex, it passes downward behind the axillary artery and over the surface of the latissimus dorsi and teres major muscles. Accompanied by the superior profunda artery, it turns backward on the inner aspect of the arm and, entering the musculo-spiral groove and traversing the interval between the internal and long and the external head of the triceps, reaches the lateral aspect of the arm. It then takes a forward course through the external intermuscular septum and becomes an occupant of the cleft between the brachioradialis and the brachialis anticus. Continuing in this space as far as the level of the external condyle of the humerus the nerve divides into its terminal branches, the *posterior interosseous* and the *radial* (Fig. 1095).

Branches.—These are: (*a*) the *cutaneous*, (*b*) the *muscular*, (*c*) the *humeral*, (*d*) the *articular* and (*e*) the *terminal*.

FIG. 1100.



Deep dissection of extensor surface of right upper extremity, showing course and branches of musculo-spiral nerve.

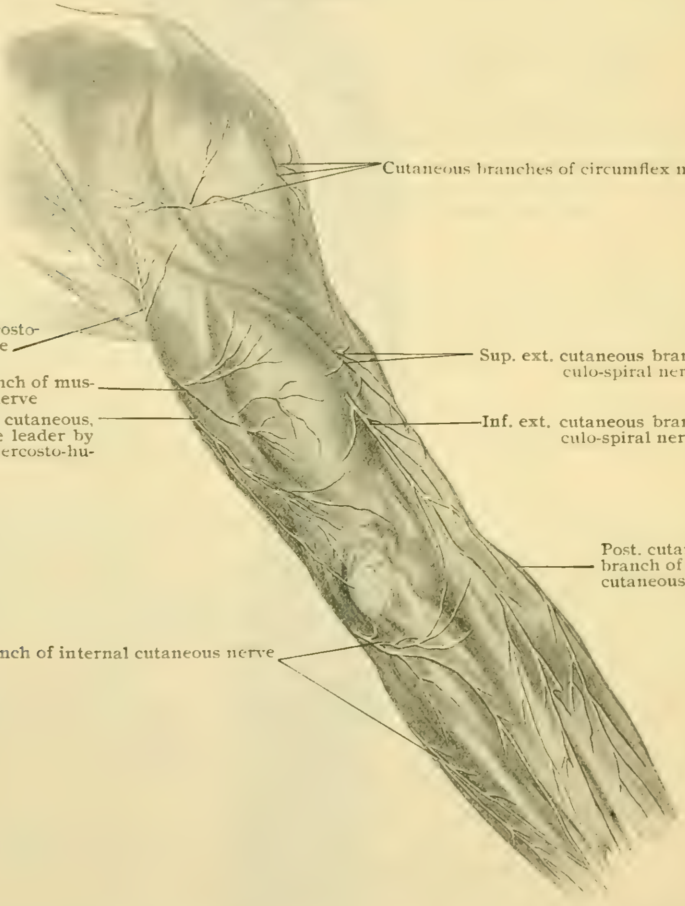
a. **The cutaneous branches** are three in number, an internal and two external. The **internal cutaneous branch** frequently arises from the musculo-spiral in common with

the branches to the long and inner heads of the triceps. It passes backward, posterior to the intercosto-humeral nerve, and after piercing the deep fascia, spreads out to be distributed to the integument over the inner head of the triceps to within a short distance of the elbow (Fig. 1101). It is accompanied by a small artery.

The **superior external cutaneous branch** (**n. cutaneus brachii posterior**) (Fig. 1101) arises from the musculo-spiral posterior to the external intermuscular septum and pierces the deep fascia below the middle of the arm, between the external head of the triceps and the brachialis anticus. It passes down with the cephalic vein and is distributed to the integument of the external anterior portion of the arm down to or slightly below the elbow.

The **inferior external cutaneous branch** (**n. cutaneus antebrachii dorsalis**) (Fig. 1102) arises and becomes superficial similarly to and in common with the superior. After passing down the

Fig. 1101.



Superficial dissection of right arm, showing cutaneous nerves of posterior surface.

arm it enters the forearm by crossing the dense fascia stretched between the olecranon and the internal condyle of the humerus. From this point it continues its downward course along the posterior aspect of the forearm as far down as the wrist or even onto the dorsum of the hand. It is distributed to the skin of the posterior portion of the arm between the areas supplied by the other cutaneous branches of the musculo-spiral and to that part of the posterior aspect of the forearm between the portions supplied by the posterior branch of the internal cutaneous and the posterior branch of the musculo-cutaneous. In the neighborhood of the wrist it inosculates with the musculo-cutaneous and sometimes with the branch to the dorsum of the hand from the ulnar.

b. The **muscular branches** (**rr. musculares**) are given off (*aa*) before the musculo-spiral enters the musculo-spiral groove and (*bb*) after leaving the groove.

aa. **Before entering the groove** branches arise for the supply of the three heads of the triceps and the anconeus.

The branch for the **long head of the triceps**, before its entrance into the muscle, breaks up into four or five filaments.

The nerve supply of the **inner head of the triceps** is usually effected by two branches, an upper and a lower. The upper is short and enters the muscle soon after leaving the musculo-spiral. The lower, called the *collateral ulnar branch*, is longer and extends for a considerable distance along the inner surface of the triceps in close association with the ulnar nerve. Posterior to the internal intermuscular septum it enters its muscle. Tiny filaments accompany the collateral ulnar artery to the capsular ligament of the elbow.

The nerves to the **outer head of the triceps** and to the **anconeus** take their origin as a single trunk. The former passes directly to the inner surface of the outer head, while the latter leaves the musculo-spiral groove and traverses the outer portion of the internal head of the triceps until the anconeus is reached.

bb. **After leaving the groove** and while lying in the cleft between the brachialis anticus and the brachio-radialis, twigs are given off for the supply of the brachio-radialis, the extensor carpi radialis longior and the brachialis anticus.

The nerve to the **brachio-radialis** enters the mesial surface of that muscle and usually supplies a filament to the capsule of the elbow.

The nerve to the **extensor carpi radialis longior** may arise either from the posterior interosseous or directly from the musculo-spiral.

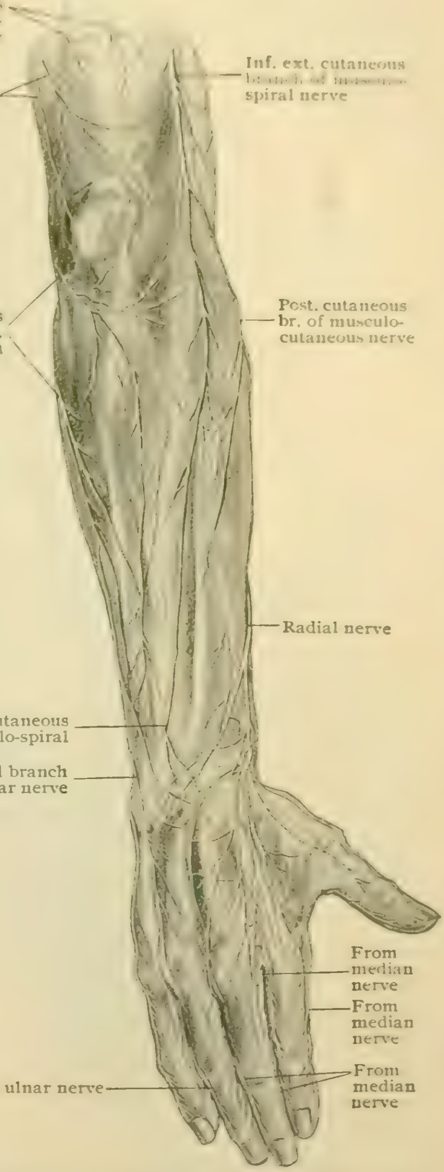
The nerve to the **brachialis anticus**, while usually present, is not constant. It enters and supplies the lateral portion of that muscle.

c. The **humeral branches** comprise one which is supplied to the periosteum of the extensor surface of the humerus and one which enters the shaft of the humerus with the nutrient artery, when the latter arises as a branch of the superior profunda.

d. The **articular branches** are destined for the elbow. They arise from the musculo-spiral as it lies between the brachialis anticus and the brachio-radialis, from the ulnar collateral nerve and from the nerve to the anconeus.

e. The **terminal branches** of the musculo-spiral arises at about the level of the external condyle and in the fissure between the brachialis anticus and the brachio-radialis. They comprise (*aa*) the *posterior interosseous* and (*bb*) the *radial*.

Fig. 1102.

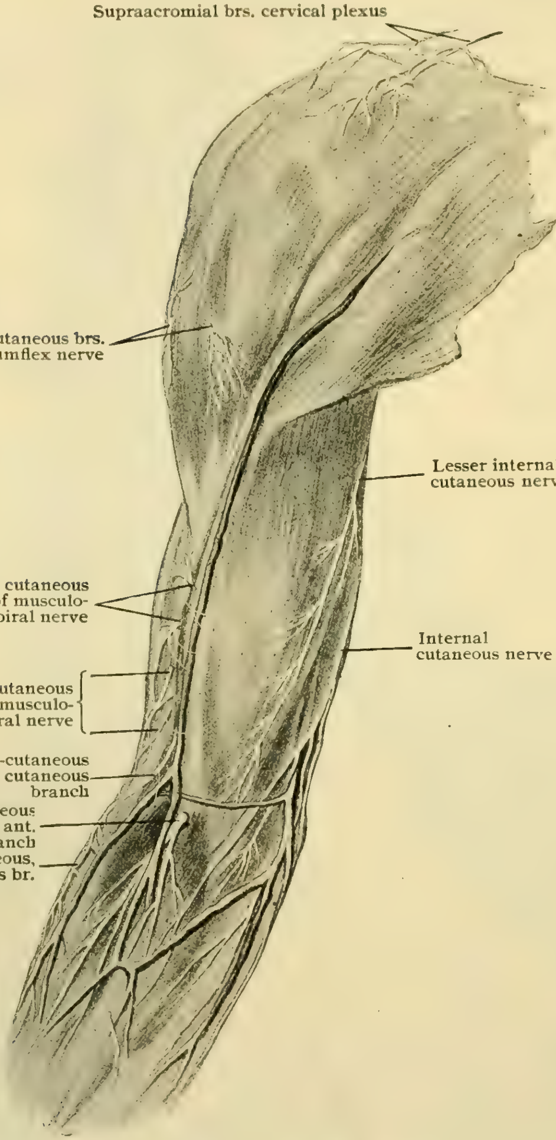


Superficial dissection of right forearm, showing cutaneous nerves of posterior surface.

aa. The **posterior interosseous nerve** (r. profundus n. radialis) (Fig. 1100) is the larger of the terminal branches and is mainly motor in function. Its fibres can be traced back to the sixth, seventh and sometimes the eighth cervical nerve. Shortly after its origin it approaches the supinator brevis, through a fissure in whose substance it makes its way to the lateral side of the radius, in this way reach-

ing the posterior aspect of the forearm. Here it takes a position between the two layers of the extensor muscles and rapidly decreases in size by giving off in quick succession branches to the neighboring muscles. As a much attenuated nerve it reaches the posterior surface of the interosseous membrane at the junction of the middle and lower thirds of the forearm. From the interval between the extensores longus and brevis pollicis it courses along the membrane, covered in turn by the extensor longus pollicis, the extensor indicis and the tendons of the extensor longus digitorum, finally reaching the dorsum of the wrist, where it presents a small gangliform swelling. In the lower fourth of its course it is sometimes called the *external interosseous nerve.*

Fig. 1103.



Superficial dissection of right arm, showing cutaneous nerves of anterior surface; cephalic vein is seen passing up to delto-pectoral interval; basilic vein pierces deep fascia at lower inner aspect of arm.

Branches of the posterior interosseous nerve comprise two sets: those given off *before* and *after* traversing the supinator brevis.

Those arising **before** the nerve enters the muscle comprise the nerves for the *extensor carpi radialis brevior* and the *supinator brevis.* The latter receives two filaments, which supply the two strata of muscle consequent upon the delamination of the supinator brevis by the posterior interosseous nerve. Quite frequently the nerve to the *extensor carpi radialis longior* arises from this portion of the posterior interosseous.

The branches given off **after leaving** the muscle include the supply of the *extensor carpi ulnaris*, the *extensor communis digitorum*, the *extensor minimi digiti*, the three *extensors of the thumb* and the *extensor indicis.*

The first three of these muscles are supplied by a branch which leaves the posterior interosseous soon after its emergence from the supinator brevis. This nerve divides into two branches, one of which is distributed to the extensor carpi ulnaris and the other to the remaining two muscles. The extensor communis digitorum receives additional innervation from a twig which arises from the posterior interosseous further down the forearm.

The *extensor ossis metacarpi pollicis* and the *extensor brevis pollicis* are innervated by a branch arising below the preceding, which breaks up into two recurrent twigs, one of which goes to each muscle.

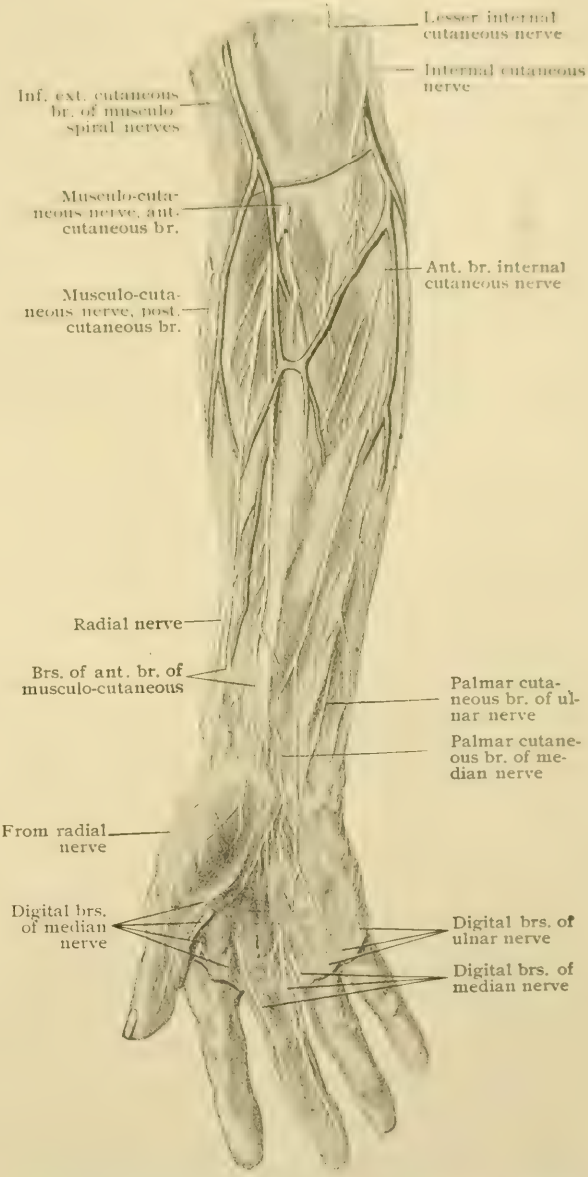
The *extensor longus pollicis* is the recipient of a small filament, which arises from the posterior interosseous a short distance below the preceding nerve.

The *extensor indicis* is supplied by the lowermost motor filament arising from the posterior interosseous.

Terminal twigs are distributed to the dorsal portion of the wrist joint, the intercarpal and carpo-metacarpal joints, the periosteum of the radius and ulna and the interosseous membrane. One of the filaments supplying the last-mentioned structure frequently inosculates with a branch from the anterior interosseous.

The filaments to the carpus are continued through the metacarpal spaces and are joined by twigs from the deep branch of the ulnar (page 1305). The joint nerves thus formed break up into two branches which accompany adjoining metacarpal bones to the metacarpo-phalangeal articulations. The branch to the first metacarpal space breaks up into seven branches (Rauber).

FIG. 1104.



Superficial dissection of right forearm and hand, showing cutaneous nerves of anterior and palmar surface.

bb. The **radial nerve** (r. superficialis n. radialis) (Fig. 1095) is smaller than the posterior interosseous and is purely sensory in its function. Its fibres originate from the sixth cervical nerve and sometimes from the fifth or seventh. From the end of the musculo-spiral it passes down the radial side of the forearm under cover of the brachio-radialis and anterior to the supinator brevis, the pronator radii teres and the radial head of the flexor sublimis digitorum. It accompanies, for the greater part of its course, the radial artery, to the radial side of which the nerve lies. At the junction of the middle and lower thirds of the forearm it begins to turn gradually backward over the radius and under the tendon of the brachio-radialis (Fig. 1095). Reaching the extensor surface of the forearm just above the wrist it divides into two diverging branches, which supply the back of the hand and the three outer digits (Fig. 1102).

Branches.—The radial nerve divides into two terminal branches, an *external* and an *internal*.

The **external or radial branch** inosculates with the musculo-cutaneous nerve and distributes filaments to the integument of the thenar eminence and the radial side of the thumb as far out as the base of the nail.

The **internal or ulnar branch** splits into two parts. The inner of these likewise undergoes dichotomous division and supplies the dorsal aspect of the adjacent surfaces of the thumb and the index finger. The outer divides similarly to the inner and is distributed to the adjoining sides of the index and middle fingers. It gives off a branch which inosculates with the adjacent filament from the dorsal branch of the ulnar nerve, so that the contiguous surfaces of the middle and ring fingers are the recipients of fibres from both the radial and ulnar nerves.

As the ulnar side of the hand is approximated the digital area of distribution of the radial nerve gradually recedes toward the wrist. On the thumb the radial extends as far out as the base of the nail, on the index finger as far as the middle of the second phalanx and on the middle finger only over the proximal portion of the first phalanx. The deficiency in these instances is supplied by twigs from the digital branches of the median nerve.

Variations.—The musculo-spiral may accompany the circumflex nerve through the quadrilateral space. It may communicate with the ulnar nerve in the upper arm. Cases are recorded in which the dorsal digital nerves to the little and the ulnar side of the ring finger were furnished by the musculo-spiral instead of by the ulnar and in which the inferior external cutaneous branch extended to the first phalanx of the ring finger and the second phalanx of the little finger. The radial nerve may supply the entire dorsum of the hand and the dorsal aspect of all the fingers, or it may be absent, the musculo-cutaneous going to the thumb and the ulnar to the remainder of the digits. The external division may send a branch to the palm. The posterior interosseous may pass over the surface of the supinator brevis and may furnish a branch to the anconeus muscle. Two instances are reported in which the posterior interosseous supplied the opposed surfaces of the middle and index fingers.

Practical Considerations.—The musculo-spiral is more frequently paralyzed than any of the other branches of the brachial plexus. Its axillary portion often suffers from crutch pressure ; and the nerve is also particularly exposed to compression where it passes between the triceps muscle and the humerus, as when the arm, during sleep, is used for a pillow. It has been injured by violent contraction of the triceps muscle, as in the act of throwing. It is frequently lacerated by the fragments in fractures of the middle of the shaft of the humerus When the lesion is in the axilla the triceps will be included in the paralysis. If the portion in the arm is affected the triceps and anconeus will escape, but the following muscles will be paralyzed : the supinators, the extensors of the hand, the extensor communis digitorum, together with the extensor indicis, the extensor minimi digiti and the extensors of the thumb. The characteristic symptom is the inability to extend the hand at the wrist (wrist drop), and this is the most common form of musculo-spiral paralysis.

THE THORACIC NERVES.

The thoracic nerves (**nn. thoracales**) (Fig. 1105) consist of twelve pairs of symmetrical nerve-cords, the upper eleven of which, because of their position in the intercostal spaces, are called *intercostal nerves*, and the twelfth, which lies below the twelfth rib and is an occupant of the abdominal wall, the *subcostal*. Since only seven ribs reach the sternum, the upper six thoracic nerves alone are continued throughout their entire course in intercostal spaces. The lower six, with the exception of the twelfth, after traversing their respective intercostal spaces proceed within the abdominal wall, through which they course to within a short distance of the median line. In accordance with the direction of the ribs, the upper nerves lie more horizontally than the lower, the latter becoming more and more oblique as the lower part of the abdominal wall is reached. As they advance from the spine, they distribute **motor filaments** to the external and internal intercostals, the subcostals, the levatores costarum, the serrati postici superior et inferior, the triangularis sterni, the external oblique, the internal oblique, the transversalis, the rectus, the pyramidalis and a portion of the diaphragm. Their **cutaneous distribution** comprises the integument of the chest and abdomen anterior to the area supplied by the posterior primary divisions of the thoracic nerves. On account of the presence of the shoulder girdle, the usual nerve distribution is modified in the upper thoracic region and the supraclavicular branches of the cervical plexus assume a function belonging to the thoracic nerves. At the lower portion of the trunk the usual arrangement is likewise altered,

the area immediately above Poupart's ligament and the pubes being innervated, not by the thoracic, but by the lumbar nerves (Fig. 1105). The supply of the cutaneous area is provided by two rows of sensory twigs, which become superficial by piercing the musculature and deep fascia of the trunk. Each of the thoracic nerves, with the exception of the first, sends out a **lateral cutaneous branch** and, with no exceptions, an **anterior cutaneous branch.** The upper thoracic nerves deviate variously from this typical arrangement, the first having no lateral and sometimes no anterior cutaneous branch, and a portion of the lateral cutaneous branch of the second, called the **intercosto-humeral nerve,** leaving the thorax to be distributed in the upper extremity. The third nerve of the series is the first to present a typical arrangement, although it, indeed, sometimes forms a loop with the lesser internal cutaneous nerve of the arm. The anterior cutaneous branches are the terminal portions of the thoracic nerves and are constant in their arrangement and distribution, with the exception of the first, which is either very small or absent and a filament from the last, which passes over the crest of the ilium to the gluteal integument.

After separating from the posterior primary divisions, the anterior primary divisions of the thoracic nerves, with the exception of the twelfth, enter the intercostal spaces by passing between the anterior costo-transverse ligaments and the external intercostal muscles. From this situation to the angles of the ribs they lie between the posterior intercostal membrane and the external intercostal muscles. Anterior to this point, they are situated between the two sets of intercostal muscles as far forward as the termination of the external set of muscles at the costo-chondral articulations, from which point forward their superficial covering is the anterior intercostal membrane and the deep the internal intercostal muscles. At first they lie within the upper part of the intercostal space, but as they advance they show a tendency to occupy the middle of the space. While accompanying the intercostal vessels, they lie below the latter and at a greater distance from the rib next above. The upper two nerves extend for a portion of their course along the inner surface of the corresponding ribs; the twelfth passes in front of the quadratus lumborum.

The **upper thoracic nerves,** as they approach the margin of the sternum, traverse the substance of the internal intercostal muscles and hold a position anterior to the internal mammary artery and the lateral portion of the triangularis sterni muscle. They terminate by piercing the anterior intercostal membrane and the pectoralis major, and ramify in the pectoral integument as the *anterior cutaneous nerves of the thorax* (Fig. 1105).

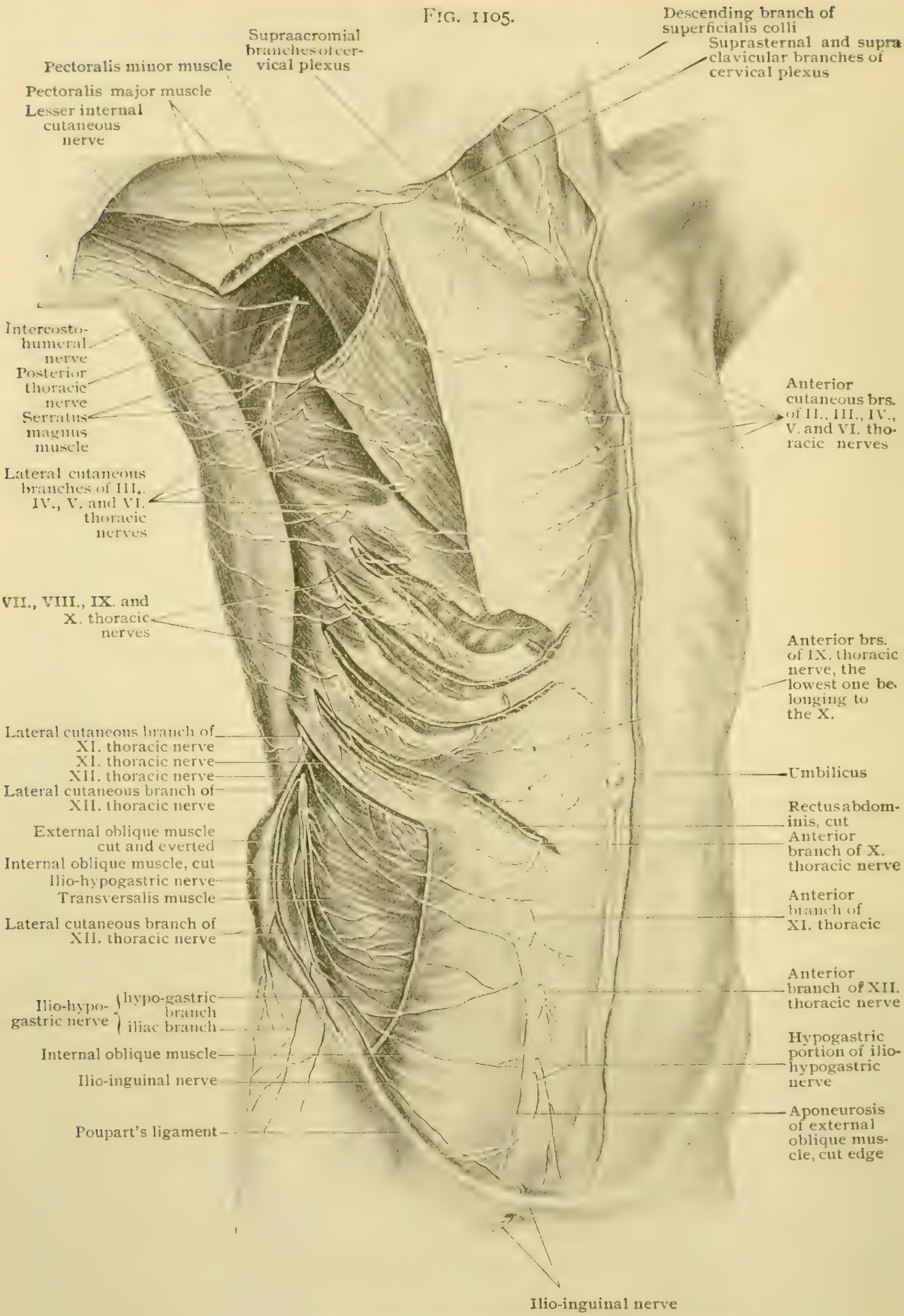
The **lower thoracic nerves** pass forward and at the anterior ends of the ribs take up a deeper position in the trunk wall by piercing the substance of the internal intercostal muscles. They then traverse the intervals between the digitations of the diaphragm and enter the abdominal wall, the seventh, eighth and ninth nerves lying behind the cartilages of the eighth, ninth and tenth ribs respectively. From this point their course is ventral, between the internal oblique and the transversalis, as far as the lateral edge of the rectus sheath, which they enter by piercing its posterior lamella. They ultimately turn forward and become superficial by traversing the rectus and its anterior aponeurotic covering, terminating as the *anterior cutaneous nerves of the abdomen* (Fig. 1105).

Communications.—Each thoracic nerve is connected with the sympathetic gangliated cord by one or two rami communicantes (Fig. 1130). Ordinarily there is no intercommunication between the upper intercostal nerves, but in rare instances a twig passes from one nerve over the inner surface of the rib next below to the subjacent nerve. The lower three or four thoracic nerves, while lying between the broad abdominal muscles are occasionally united to one another, sometimes to the extent of forming a small plexus.

Peculiar thoracic nerves.—The first, second, twelfth, and sometimes the third, thoracic nerves present peculiarities which differentiate them from the others.

The **first thoracic nerve** sends a large portion of its fibres to the brachial plexus, thus suffering great reduction in its size. Although occasionally a very small branch to the axilla is found, a lateral cutaneous branch is rare, it being generally held that the contribution of this nerve to the brachial plexus is the

FIG. 1105.



Dissection showing thoracic, ilio-hypogastric and ilio-inguinal nerves.

equivalent of a lateral cutaneous branch. In addition to the lateral cutaneous, the anterior cutaneous branch may also be wanting, the area typically supplied by the absent branch being served by the descending branches of the cervical plexus.

The **second thoracic nerve** sometimes contributes fibres to the brachial plexus. The posterior ramus of its lateral cutaneous branch is called the *intercosto-humeral nerve*.

The **intercosto-humeral nerve** (n. intercostobrachialis) (Fig. 1105) is quite large and pierces the inner axillary wall between the second and third ribs. Entering the axilla, it crosses that space toward the arm and communicates with the lesser internal cutaneous nerve from the brachial plexus. After piercing the deep fascia, the intercosto-humeral nerve supplies the internal and posterior portion of the integument of the upper half of the arm, a few of its fibres extending slightly beyond the margin of the scapula.

The **third thoracic nerve** may form an inosculation with the lesser internal cutaneous nerve.

The **twelfth thoracic** or the **subcostal nerve** lies below the last rib and therefore does not occupy an intercostal space, but passes outward below the external arcuate ligament and anterior to the quadratus lumborum muscle. It contributes a twig to the lumbar plexus which passes down to join the first lumbar nerve. Its lateral cutaneous branch is not confined in its distribution to the abdominal wall, since, after piercing the internal oblique and sending a filament to the lower digitation of the external oblique, it penetrates the substance of the latter muscle at a point from 2–10 cm above the crest of the ilium and supplies the integument of the gluteal region as far down as the upper margin of the great trochanter (Fig. 1083).

Branches of the thoracic nerves are: (1) the *muscular* and (2) the *cutaneous*.

1. The **muscular branches** (rr. musculares) may be divided into two groups: (*a*) the *thoracic* and (*b*) the *abdominal*.

a. The **thoracic muscular branches** arise from the first to the seventh inclusive and supply the external and internal intercostals, the subcostals, the levatores costarum, the serratus posticus superior, the triangularis sterni and the rectus abdominis.

The branches to the *intercostal* and *subcostal muscles* are distributed throughout the course of each nerve. The first to be given off is the largest and courses forward for some distance along the lower part of the intercostal space. The others vary greatly in number and size.

The branches to the *levatores costarum* consist of fine threads, one arising from each nerve beyond the anterior costo-transverse ligament. They pierce the external intercostal muscles and enter the deep surface of the muscles which they supply.

The branches to the *serratus posticus superior* arise from the upper four nerves. After piercing the external intercostal muscles they pass along the outer margin of the ilio-costalis and supply the four digitations of their muscle.

The branches to the *triangularis sterni* are terminal continuations of the third to the seventh intercostal nerves. After piercing the internal intercostal muscles they pass forward between the triangularis sterni and the internal intercostals or, in the case of the seventh, anterior to the transversalis muscle. In addition to supplying the triangularis sterni the seventh sends fibres to the first digitation of the transversalis.

The branches to the *rectus* arise from the fifth, sixth and seventh and enter the deep surface of the muscle.

b. **The abdominal muscular branches** arise from the eighth to the twelfth inclusive and are distributed to the intercostals, the subcostals, the levatores costarum, the serratus posticus inferior, the external obique, the internal oblique, the transversalis, the rectus, the pyramidalis and the diaphragm.

The branches to the *intercostal*, *subcostal* and *levatores costarum muscles*, with the exception of arising from the lower thoracic nerves, resemble in origin, course and distribution those arising from the upper nerves.

The branches to the *serratus posticus inferior* are larger than those to the serratus posticus superior. They arise from the ninth, tenth and eleventh nerves and pass around the lateral margin of the ilio-costalis to reach their destination.

The branches to the *external oblique*, the *internal oblique* and the *transversalis* comprise numerous fine twigs which supply those muscles and arise from the lower five thoracic nerves as they course forward between the transversalis and the internal oblique.

The branches to the *rectus* arise from the eighth to the twelfth nerves inclusive after they have entered the sheath and as they pierce the rectus on their way to the surface.

The branches to the *pyramidalis* are derived from the twelfth thoracic and first lumbar nerves.

The branches to the *diaphragm* are supplied to its costal portion and consist of fine filaments which are given off by the lower six thoracic nerves (Luschka).

2. The **cutaneous branches** are larger than the muscular and consist of two sets: (*a*) the *lateral cutaneous* and (*b*) the *anterior cutaneous*.

a. The **lateral cutaneous branches** (**rr. cutanei laterales**) consist of two series, an upper and a lower, the former originating from the first to the sixth and the latter from the sixth to the twelfth thoracic nerves. Those of the upper series pierce the external intercostal muscles and those of the lower the external oblique in a line situated midway between the mammary and mid-axillary lines. The upper seven pass between the digitations of the serratus magnus and the lower between the digitations of the latissimus dorsi and the external oblique. The one arising from the twelfth pierces the musculature of the external oblique. Each lateral cutaneous nerve divides into (*aa*) an anterior and (*bb*) a posterior branch (Fig. 1083).

aa. The **posterior branches** (**rr. posteriores**) are smaller than the anterior. They wind around the edge of the latissimus dorsi and supply the integument of the lateral area of the trunk as far back as the anterior margin of the region supplied by the posterior primary divisions of the thoracic nerves. The branches from the third to the sixth inclusive have fibres which are distributed over the lateral portion of the scapula.

bb. The **anterior branches** (**rr. anteriores [pectorales et abdominales]**) are of considerably greater size than the posterior. Those from the second to the seventh pass toward the lateral margin of the pectoralis major and supply the integument of this region as far forward as the nipple. Branches (**rr. mammarii laterales**) from the fourth, fifth, and sixth send filaments to the skin and substance of the mammary gland. Those from the seventh to the eleventh supply the integument of the abdomen as far anterior as the lateral margin of the rectus. The anterior branch from the twelfth has a filament which passes over the iliac crest to the integument of the gluteal region, usually sending a branch as far as the great trochanter. It maintains a more or less even balance with the corresponding branch of the first lumbar nerve, each supplying any deficiency in the other.

b. The **anterior cutaneous branches** (**rr. cutanei anteriores**) are the terminal fibres of the thoracic nerves. Those from the upper six (**rr. cutanei pectorales anteriores**) pierce the pectoralis major near the lateral margin of the sternum and supply the adjacent integument of the thorax. Filaments (**rr. mammarii mediales**) are distributed to the skin of the mesial portion of the mammary gland. The anterior cutaneous branches from the lower six (**rr. cutanei abdominales anteriores**) vary in position. They consist of the terminal filaments which perforate the anterior portion of the rectus sheath at a situation anywhere between the lineæ alba and semilunaris. Those from the seventh become superficial near the ensiform cartilage, those from the tenth supply the region of the umbilicus and those from the twelfth are distributed to the area located midway between the umbilicus and the pubic crest (Fig. 1105).

Practical Considerations.—Of the branches of the thoracic spinal nerves, the anterior or intercostals suffer most frequently from sensory disturbances, and the posterior from motor disturbances. *Intercostal neuralgia* may result from pressure, as from aneurism or spinal disease, or it may be due to injury. The lower intercostals enter into the supply of both the thoracic and the anterior abdominal walls, the pleura also being supplied by them. Pain referred to the abdominal wall and rigidity of the abdominal muscles may therefore be due to diseases within the chest, as pleurisy. Such diseases in the upper part of the chest may cause pain to extend down the arm along the intercosto-humeral nerve, which is the lateral cutaneous branch of the second intercostal nerve, or sometimes of the second and third intercostals. The pain of intercostal neuralgias often becomes intense, especially after violent expiratory efforts, as in coughing and sneezing; not infrequently after the pain ceases, *herpes zoster* appears in the line of the nerve affected. This may be a trophic disturbance or an extension of the inflammation along the nerve endings to the skin. *Mastodynia*, or the so-called "irritable breast of Cooper," is due to intercostal neuralgia, and occurs in the female during the child-bearing period.

The lower intercostal nerves, with the ilio-hypogastric and ilio-inguinal, supply the muscles of the abdominal wall, and are frequently injured by the incisions made in abdominal operations, thus leading to more or less impairment of the muscles supplied and favoring the later development of hernia. The incision should therefore, so far as possible, be made in the line of the fibres of the muscles (page 535).

The intercostal nerves continue their oblique line through the abdominal muscles. The pain from Pott's disease is often transferred along the nerves coming from the affected segment of the cord. In this way pain in the abdominal region may

result from this disease, and an abdominal lesion may be suspected; this has occurred more particularly in children. A feeling of tightness is sometimes observed about the abdomen, corresponding to the course of one or more pairs of these nerves, and may be due to impaired sensation in them. Since the abdominal muscles are supplied chiefly by the seven lower intercostal nerves, they are concerned in respiration. When they are contracted as in general peritonitis, the lower ribs become immobile, and breathing takes place chiefly in the upper portion of the chest.

THE LUMBAR PLEXUS.

The lumbar plexus (**plexus lumbalis**) lies in the substance of the psoas magnus muscle, anterior to the transverse processes of the lumbar vertebræ, and consists of a series of loops formed by the anterior primary divisions of the first, second and third lumbar nerves, the smaller subdivision of the fourth lumbar and sometimes a branch from the twelfth thoracic nerve. The remainder and major portion of the fourth lumbar nerve unites with the entire anterior primary division of the fifth to form a conjoint trunk, the **lumbo-sacral cord** (truncus lumbosacralis), which passes into the pelvis to become a constituent of the sacral plexus (Fig. 1106). The lumbar nerves increase in thickness from above downward, the first being only 2.5 mm., while the fifth attains a diameter of 7 mm. The length of the nerves from their exit at the intervertebral foramina to their point of division varies considerably, in the case of the first being 1 mm. or less, of the second 10 mm. and of the third from 20–25 mm.

Constitution and Plan.—In forming the plexus (Fig. 1106), the first lumbar nerve divides almost immediately after its exit from the vertebral column into an upper and a lower branch. The upper, which may receive a contribution from the twelfth thoracic nerve, becomes the *ilio-hypogastric* and *ilio-inguinal nerves.* The lower branch, near the body of the second lumbar vertebra joins the upper part of the second lumbar nerve, which, like the first, divides into an upper and a lower branch. The union of the lower branch of the first and the upper branch of the second results in the formation of the *genito-crural nerve.* Sometimes fibres from the first aid in the formation of the anterior crural and obturator nerves. The lower branch of the second, all of the third and that part of the fourth which enters the lumbar plexus divide into smaller **anterior** and larger **posterior** trunks. From the union of the anterior branches of these three the *obturator nerve* is formed, and from the union of the posterior results the *anterior crural nerve.* The posterior portions of the second and third nerves give off from their dorsal aspect small branches which unite into the *external cutaneous nerve.* The *accessory obturator nerve*, when it exists, arises from the third and fourth lumbar between the roots of the anterior crural and obturator nerves.

Fig. 1106.

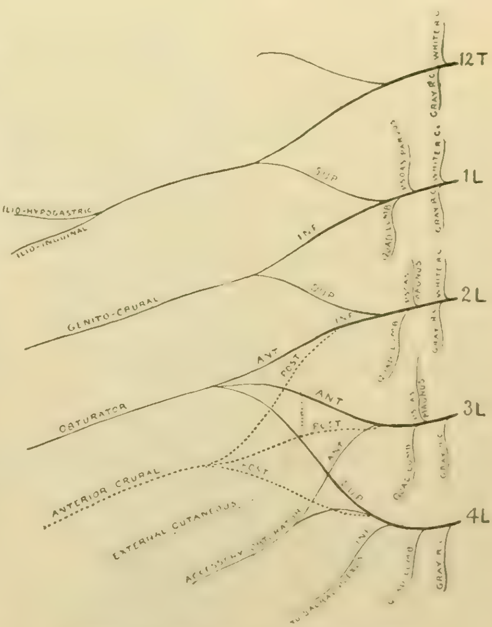


Diagram illustrating plan of lumbar plexus.

Communications.—All of the lumbar nerves receive gray rami communicantes from the gangliated cord of the sympathetic; and from the first and second, and possibly the third and fourth, white rami communicantes pass to the lumbar portion of the gangliated cord.

Variations.—That portion of the fourth lumbar nerve, or *n. furcalis*, which joins the lumbosacral cord, is usually less than half of the parent trunk, but varies from one-twentieth to nine-tenths. When large, it may be joined by a branch from the third lumbar, and when small the fifth lumbar may contribute to the lumbar plexus, the fibres going to the anterior crural alone or to the anterior crural and obturator nerves. The branch to the lumbosacral cord from the fourth lumbar may be absent and in such an event the fifth is the only furcal nerve sending fibres to both the lumbar and the sacral plexus. It is thus possible to have as furcal nerves the third and fourth, the fourth alone, the fourth and fifth or the fifth alone, and according to the high or low position of these there is found a corresponding origin of the branches of the lumbar plexus. In this manner are accounted for the *high* and *low*, or *prefixed* and *postfixed* types of plexus.

Branches of the lumbar plexus are :

1. The Muscular
2. The Ilio-Hypogastric
3. The Ilio-Inguinal
4. The Genito-Crural
5. The External Cutaneous
6. The Obturator
7. The Accessory Obturator
8. The Anterior Crural

1. The Muscular Branches.

The **muscular branches** (rr. musculares) supply the quadratus lumborum, the psoas magnus and the psoas parvus.

The branches to the *quadratus lumborum* arise from the upper three or four lumbar nerves, and sometimes from the last thoracic, and pass directly into the quadratus.

The branches to the *psoas magnus* arise mainly from the second and third lumbar nerves, there sometimes being additional ones from the first and fourth. They pass directly into the muscle.

The branches to the *psoas parvus* consist of filaments from the first or second lumbar nerve which reach the muscle by piercing the underlying psoas magnus.

2. The Ilio-Hypogastric Nerve.

The **ilio-hypogastric nerve** (n. iliohypogastricus) (Fig. 1107) is the uppermost branch of the plexus and is somewhat larger than its associate, the ilio-inguinal. Whilst it derives the major portion and sometimes all of its fibres from the first lumbar nerve, it usually receives others from the twelfth and occasionally the eleventh thoracic. It emerges from the lateral margin of the upper portion of the psoas magnus and runs, below and parallel with the twelfth thoracic nerve, outward and downward, posterior to the kidney and anterior to the quadratus lumborum. Reaching the crest of the ilium, it pierces the transversalis muscle and occupies the intermuscular space between the internal oblique and the transversalis. After coursing along this interval as far as the middle of the iliac crest, it divides into its terminal branches, (*a*) the *iliac* and (*b*) the *hypogastric*, which correspond morphologically with the lateral and anterior cutaneous branches of the thoracic nerves. There are also some (*c*) *muscular branches*.

a. The **iliac branch** (r. cutaneus lateralis) pierces the internal and external obliques about the middle of the iliac crest and is distributed to the integument of the anterior gluteal region which covers the gluteus medius and the tensor fasciæ femoris (Fig. 1053). It forms an inosculation with the lateral cutaneous branch of the twelfth thoracic nerve and maintains an even balance with it, deficiency in the development of either being recompensed for by a compensating increase in size of the other.

b. The **hypogastric branch** (r. cutaneus anterior) continues the direction and course of the main trunk between the transversalis and the internal oblique almost to the linea alba. Near the anterior superior spine of the ilium it forms an inosculation with the ilio-inguinal nerve. As it approaches the region of the internal abdominal ring it begins to push its way gradually through the internal oblique and gain the interval between the internal and the external oblique (Fig. 1105). A short distance superior and internal to the external abdominal ring it traverses a tiny foramen in the aponeurosis of the external oblique and breaks up into fibres of termination which supply the integument of the suprapubic region.

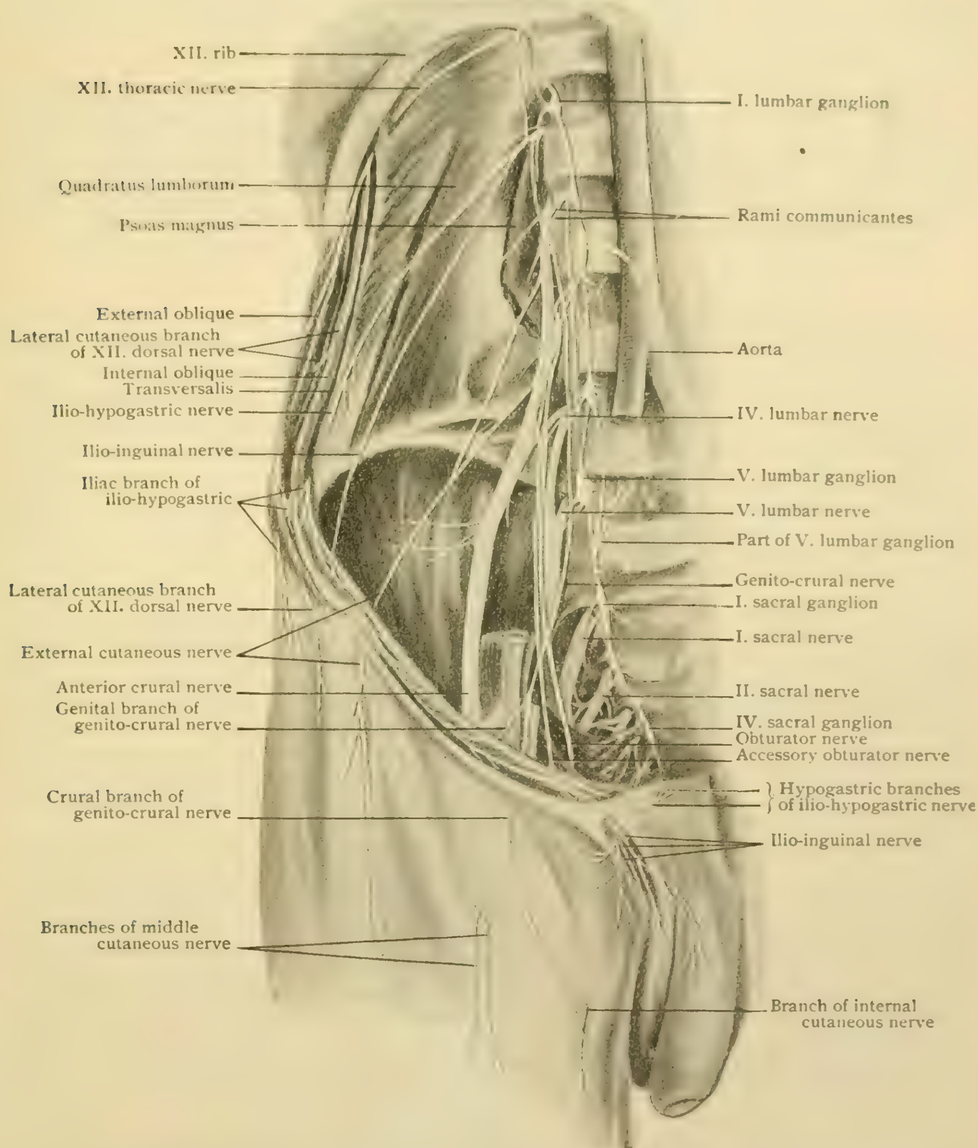
c. **Muscular branches** (rr. musculares) arise from the hypogastric branch in its course through the abdominal wall and supply the transversalis, the internal oblique and the external oblique.

Variations.—The iliac branch may be absent, its place being taken by the lateral cutaneous branch of the twelfth thoracic nerve. The hypogastric branch may mosculate with the twelfth thoracic and may supply the pyramidalis muscle.

3. The Ilio-Inguinal Nerve.

The ilio-inguinal nerve (**n. ilioinguinalis**) (Fig. 1107) is the second branch of the lumbar plexus and is somewhat smaller than the ilio-hypogastric. Its fibres usually arise from the first lumbar nerve, with accessions from the twelfth thoracic.

Fig. 1107.



Deep dissection, showing nerves arising from lumbar plexus and lower part of sympathetic gangliated cord.

Sometimes it arises entirely from the twelfth thoracic or from the second lumbar or from the loop between the first and second lumbar nerves. It occasionally forms a common trunk of considerable length with the ilio-hypogastric. In the early part

of its course it parallels the ilio-hypogastric, appearing at the edge of the psoas magnus, crossing the quadratus lumborum behind the kidney and piercing the transversalis to reach the intermuscular cleft between the transversalis and the internal oblique (Fig. 1105). While in the last situation it inosculates with the ilio-hypogastric and continues forward to enter the inguinal canal, from which it emerges either through the external abdominal ring or through the external pillar of the ring, infero-lateral to the spermatic cord.

Some of the **branches** of the ilio-inguinal supply the integument of the upper inner portion of the thigh. Others (**nn. scrotales anteriores**) are distributed to the pubic region and the base of the penis and scrotum or, in the female (**nn. labiales anteriores**), the mons Veneris and labia majora. Tiny motor filaments (**rr. musculares**) are given off in the course of the nerve to the transversalis, the internal oblique and the external oblique.

Variations.—The ilio-inguinal may be small and terminate near the iliac crest by joining the ilio-hypogastric, which then sends off an inguinal branch with the course and distribution of the absent portion of the ilio-inguinal. The nerve may be absent entirely and replaced by either branch, usually the genital, of the genito-crural. It may give off a lateral cutaneous or iliac branch for the supply of the integument in the region of the anterior superior spine of the ilium. The ilio-inguinal may partially replace the genital branch of the genito-crural or, in rare instances, the external cutaneous.

4. The Genito-Crural Nerve.

The genito-crural nerve (**n. genitofemoralis**) is formed by two roots, one of which arises from the loop between the first and second lumbar nerves and the other directly from the second lumbar nerve, its fibres being derivatives of the first and second lumbar. The nerve passes obliquely forward through the musculature of the psoas magnus, near the inner border of whose anterior surface it emerges opposite the body of the third lumbar vertebra, where division into the two **terminal branches,** (*a*) the *genital* and (*b*) the *crural*, takes place (Fig. 1107). Occasionally division occurs earlier in the course of the nerve, in the substance of the psoas, and under these circumstances the two branches emerge separately from the muscle. In addition to the terminal branches there are some (*c*) *muscular twigs*.

a. The **genital branch** (**n. spermaticus externus**) obtains its fibres from the first lumbar nerve. Passing downward on the inner margin of the psoas magnus, it crosses the external iliac artery and bends forward toward the posterior wall of the inguinal canal. It then enters the canal either by piercing the infundibuliform or the transversalis fascia and, lying internal to and below the spermatic cord, traverses the canal and enters the scrotum (Fig. 1108). It sends a filament to the external iliac artery and supplies the cremaster muscle, the skin of the scrotum and the integument of the thigh immediately adjacent to the scrotum. In the female it is smaller and accompanies the round ligament of the uterus to the labium majus, to whose integument it is distributed. It communicates with the ilio-inguinal nerve and with the spermatic plexus of the sympathetic.

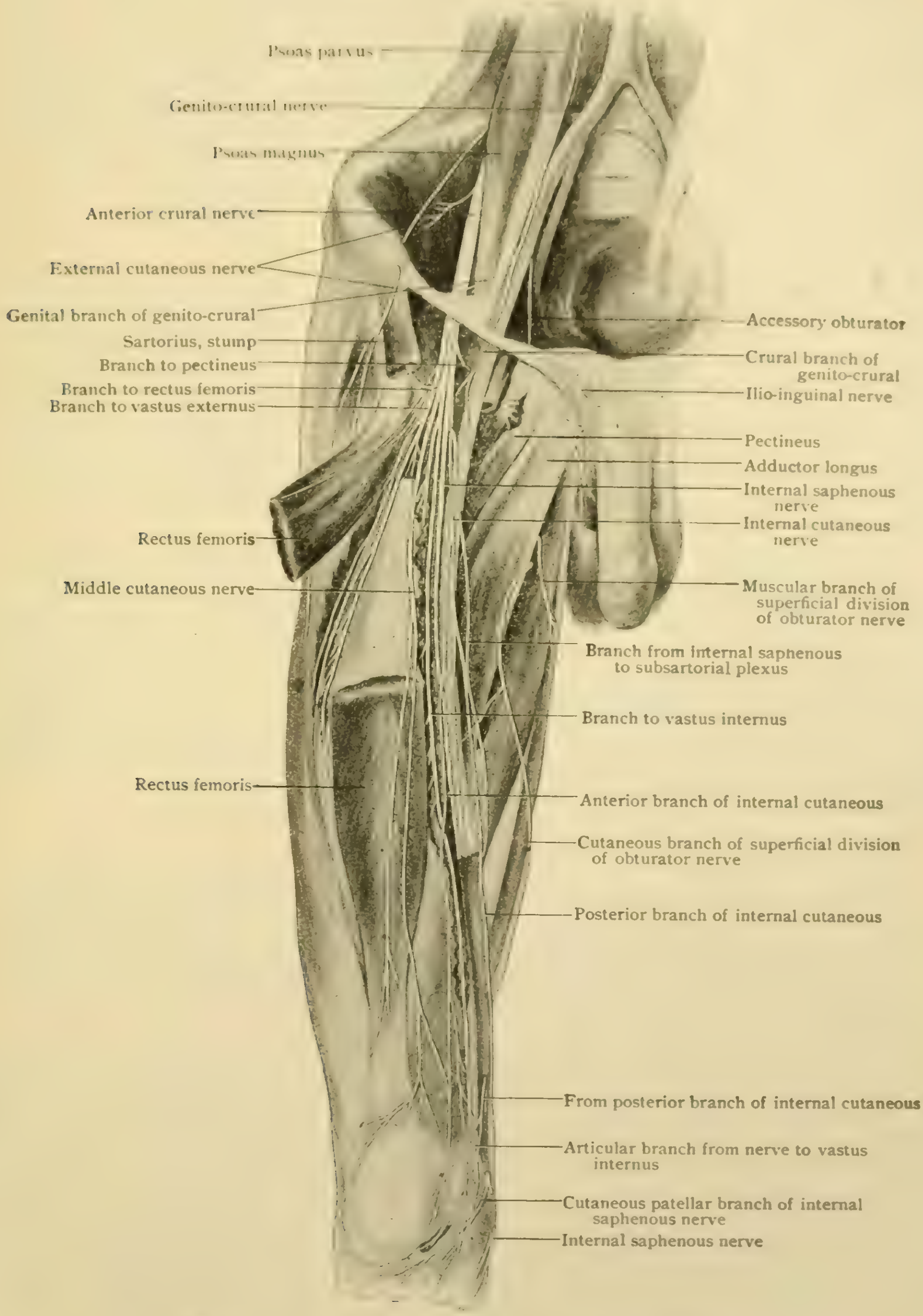
b. The **crural branch** (**n. lumboinguinalis**) consists of fibres from the second lumbar nerve. It courses down on the anterior surface of the psoas magnus, lateral to the genital branch and to the external iliac vessels, and enters the thigh by passing beneath Poupart's ligament. One of its filaments traverses the saphenous opening, while the remainder of the nerve pierces the fascia lata to the outer side of the opening (Fig. 1107). Its **branches** vary considerably in size and length and are distributed to the cutaneous area of the upper anterior part of the thigh between the regions supplied by the external cutaneous and ilio-inguinal nerves, sometimes extending downward as far as the middle of the thigh. It furnishes a minute branch to the femoral artery and inosculates with the middle cutaneous nerve.

c. **Muscular branches** to the internal oblique and transversalis are frequently given off by the genital branch.

Variations.—The genital and crural branches may arise as separate offshoots of the lumbar plexus and either of them may be derived entirely from the first or the second lumbar nerve. The genital branch sometimes contains fibres from the twelfth thoracic. Absence of the genito-crural or of either branch may occur, the fibres of the genital branch being contained in the ilio-inguinal and those of the crural in the external cutaneous or the anterior crural. The genital branch may replace or reinforce the ilio-inguinal nerve; the crural branch may act similarly toward the external or the middle cutaneous nerve. A specimen found in the anatomical laboratory of the University of Pennsylvania showed unusually extensive distribution of the crural

branch. It was larger than normal, its size being that of the normal external cutaneous, and it emerged from the deep fascia below Poupart's ligament directly anterior to the femoral vein. It

FIG. 1168.



Dissection of right thigh, showing branches of anterior crural nerve.

divided into a smaller mesial and larger lateral branch and was distributed to the integument of the thigh as far down as the junction of the middle and lower thirds.

5. The External Cutaneous Nerve.

The external cutaneous nerve (**n. cutaneus femoris lateralis**) (Fig. 1109) arises at the posterior aspect of the lumbar plexus from the second and, to a less extent, the third lumbar nerve. It may arise from the first and second, from the second alone or may derive a majority of its constituent fibres from the third. It passes obliquely downward and outward beneath the lateral margin of the psoas magnus and over the iliacus muscle, through the iliac fossa, covered by the iliac fascia. After crossing the deep circumflex iliac artery it enters the thigh beneath Poupart's ligament, mesial to the anterior superior spine of the ilium, and passes over, sometimes through or under, the pointed tendinous origin of the sartorius. The nerve then descends in the thigh beneath the fascia lata and soon divides into (*a*) an *anterior* and (*b*) a *posterior* terminal branch (Fig. 1110).

a. The **anterior branch** (**r. anterior**) follows a downward course in the thigh in a tubular canal in the fascia lata, from which it emerges at a point 10–15 cm. below the anterior superior iliac spine. It continues downward anterior to the vastus externus muscle and is distributed to the integument of the antero-lateral aspect of the thigh as far as the knee. Numerous collateral branches are given off, the majority of which arise from its lateral edge and supply the skin over the ilio-tibial band. The main trunk may extend quite to the knee and become a participant in the formation of the patellar plexus.

b. The **posterior branch** (**r. posterior**) passes obliquely backward through the fascia lata and breaks up into several branches which are distributed to the integument over the tensor fasciæ femoris and the lower portion of the gluteal region. The uppermost filaments are crossed by twigs from the lateral cutaneous branch of the twelfth thoracic nerve.

Variations.—The external cutaneous may be associated with the anterior crural until after Poupart's ligament has been passed. A branch of the genito-crural may replace the posterior branch. In one case a branch of the ilio-inguinal took the place of the external cutaneous.

Three specimens found in the anatomical rooms of the University of Pennsylvania showed decided anomalies. In one the nerve passed beneath Poupart's ligament at a point midway between the anterior superior spine of the ilium and the femoral artery. In another the nerve of the right side resembled in position the one just mentioned, while the left was apparently absent, its place being taken by a branch of the anterior crural. In the third the posterior branch emerged from beneath Poupart's ligament 5 cm. to the inner side of the anterior superior iliac spine. The anterior branch formed a common trunk with the external branch of the middle cutaneous nerve. From the joint trunk a small branch passed to join the internal branch of the middle cutaneous after the latter had pierced the sartorius muscle.

6. The Obturator Nerve.

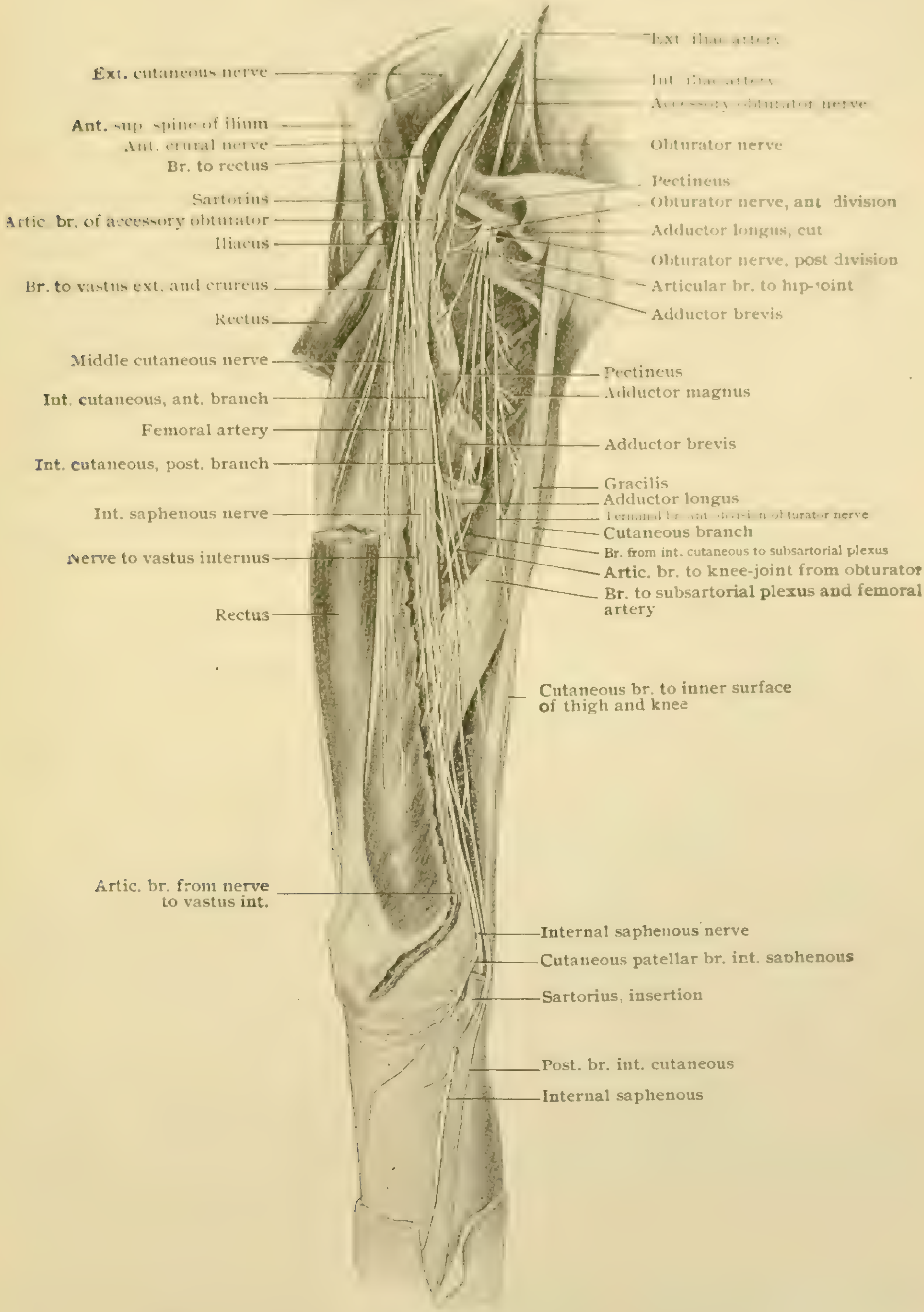
The obturator nerve (**n. obturatorius**) (Fig. 1109) is composed of fibres which arise from the second, third and fourth lumbar nerves, the fourth supplying the largest and the second the smallest contribution, the latter sometimes being absent entirely. Occasionally additional roots are derived from the first and fifth lumbar nerves, and sometimes the nerve arises, in the high form of plexus, from the first, second and third lumbar nerves.

The three roots having united in the substance of the psoas magnus, the nerve passes vertically downward and emerges, the only constant branch of the plexus to do so, from the mesial margin of the psoas muscle opposite the brim of the true pelvis. Lying posterior to the common and lateral to the internal iliac vessels, the obturator nerve courses along the antero-lateral wall of the pelvis below the ilio-pectineal line, above the obturator vessels and upon the inner surface of the pelvic fascia. It escapes from the pelvis through the obturator canal in the obturator membrane and divides into its terminal branches, either while still within the foramen or shortly after emerging from it. These branches are separated from each other first by the anterior fibres of the obturator externus muscle and later by the adductor brevis muscle. They supply the adductor muscles, the hip and knee joints and the integument of the mesial aspect of the thigh.

Branches.—The obturator gives off: (*a*) a *branch to the obturator externus muscle* and then divides into its *terminal branches*, (*b*) the *anterior* and (*c*) the *posterior*.

a. **The branch to the obturator externus** arises within the pelvis from the inner surface of the obturator nerve. It accompanies the parent trunk through the foramen, immediately after

FIG. 1109.



Dissection of right thigh, showing branches of anterior crural and obturator nerves.

escaping from which it dips down in the interval between the obturator membrane and the obturator externus muscle. From this situation its fibres pass through the deep surface into the substance of the muscle.

b. The **anterior branch** (r. anterior), the more superficial, descends in front of the obturator externus and adductor brevis muscles and between the pectineus and the adductor longus. Having reached the interval between the adductores brevis and longus it separates into its terminal branches.

Branches of the anterior division are: (*aa*) the *articular*, (*bb*) the *muscular*, (*cc*) the *cutaneous*, (*dd*) the *communicating* and (*ee*) the *vascular*.

aa. The **articular branch** leaves the obturator at the inferior margin of the obturator foramen and passes through the cotyloid notch to supply the hip joint.

bb. The **muscular branches** supply the adductores brevis and longus and the gracilis.

The branch to the *adductor brevis* enters the muscle near the upper margin of the anterior surface.

The branch to the *adductor longus* enters the posterior surface of the muscle and sometimes gives off the *cutaneous branch* of the obturator (see below).

The branch to the *gracilis* passes inward behind the adductor longus and enters the deep surface of its muscle.

cc. The **cutaneous branch** (r. cutaneus) (Fig. 1110) is variable in size and maintains an approximately even balance with the internal cutaneous branch of the anterior crural. Sometimes arising from the nerve to the adductor longus, it becomes superficial in the middle of the thigh by passing between the adductor longus and the gracilis. It supplies the integument of the lower inner portion of the thigh and beneath the sartorius forms an inosculation with branches of the internal cutaneous and internal saphenous nerves, called the **subsartorial** or **obturator plexus.**

dd. The *communicating branches* consist of twigs which unite in the pelvis with the accessory obturator nerve and in the thigh anterior to the capsular ligament of the hip joint with the anterior crural.

ee. The *vascular branch* enters Hunter's canal along the mesial edge of the adductor longus and spreads out over the lower portion of the superficial femoral artery.

c. The **posterior branch** (**r. posterior**), the deeper, pierces the anterior fibres of the obturator externus muscle and descends in the cleft between the adductores brevis and magnus, and in the latter situation splits into its terminal twigs.

Branches of the posterior division are: (*aa*) the *muscular* and (*bb*) the *articular*.

aa. The **muscular branches** supply the obturator externus, the adductor magnus and the adductor brevis.

The branch to the *obturator externus* is additional to the twig from the main trunk of the obturator which supplies that muscle. It arises from the posterior surface of the posterior division and enters the superficial surface of the muscle.

The branch to the *adductor magnus* is associated with the branch to the knee and leaves the latter as the conjoint nerve passes through the substance of the adductor magnus.

The branch to the *adductor brevis* enters the posterior surface of the muscle and is present only when the usual branch from the anterior division is absent.

bb. The **articular branches** are destined for the supply of the hip and knee joints.

The branch to the *hip joint* consists of one or two fine twigs which pass beneath the pectineus to be distributed to the antero-median portion of the capsular ligament.

The branch to the *knee joint* or the **geniculate branch** continues the course of the posterior division. Associated with the nerve to the adductor magnus, it courses down the anterior surface to the adductor magnus, which it pierces at the lower portion of the thigh. Here its muscular fibres terminate in the adductor magnus while the articular portion enters the popliteal space. The nerve continues downward on the popliteal artery, to which it distributes filaments, and finally terminates by entering the knee joint through the posterior ligament.

Variations.—In rare instances the root from the second lumbar nerve is absent. Branches are sometimes given off to the obturator internus and to the pectineus. Tiny branches have been found going to the obturator artery and to the periosteum of the pelvic surface of the os pubis. In a cadaver dissected in the anatomical laboratory of the University of Pennsylvania the obturator of the right side divided into the usual anterior and posterior branches, but both of them passed posterior to the adductor brevis. On the left side the normal arrangement was present. In another specimen in the same laboratory the branch from the main trunk to the obturator externus muscle lay to the outer instead of the inner side of the obturator nerve.

7. The Accessory Obturator Nerve.

The accessory obturator nerve is an inconstant branch of the lumbar plexus, being found in 29 per cent. of the cadavers examined (Eisler). Its fibres arise from the third and fourth lumbar nerves, with an occasional root from the fifth; it may be derived from the third alone. The roots of origin are situated between those of the anterior crural and the obturator, and the nerve may be intimately associated with either of these two, usually the former.

The accessory obturator courses downward mesial to the psoas magnus and beneath the iliac fascia, and leaves the pelvis by passing over the horizontal ramus of the pubes and under the pectineus. In the latter situation it breaks up into its **branches**, one of which (*a*) supplies the pectineus, another (*b*) the hip joint, while the third (*c*) inosculates with the anterior division of the obturator nerve. Sometimes it is very small and its fibres pass only to the hip joint. By means of its inosculation with the obturator some of its fibres may reach the adductores longus and brevis and gracilis muscles, as well as the integument of the inner region of the thigh.

8. The Anterior Crural Nerve.

The anterior crural or **femoral nerve** (n. femoralis) (Fig. 1108), the largest branch of the lumbar plexus, arises from the first, second, third and fourth lumbar nerves. It passes obliquely downward and outward, posterior to the psoas magnus, and emerges from beneath the middle of the lateral margin of that muscle. Thence it continues its course between the outer edge of the psoas and the mesial edge of the iliacus, covered by the iliac fascia, as far as Poupart's ligament, under which it passes to become an occupant of the anterior portion of the thigh. The nerve lies to the outer side of the external iliac and femoral vessels, in the abdomen being separated from them by the psoas magnus, but, as the thigh is reached, gradually nearing them until in Scarpa's triangle the nerve lies in apposition to the femoral sheath. In the immediate neighborhood of Poupart's ligament, the anterior crural nerve rapidly splits up into a number of

Branches, which may be grouped into (*b*) a *superficial division*, principally sensory, and (*c*) a *deep division*, mainly motor. In addition there are (*a*) branches arising *from the main trunk*.

a. The **branches from the main trunk** consist of (*aa*) the *muscular branches* and (*bb*) the *nerve to the femoral artery*.

aa. The **muscular branches** supply the iliacus, the psoas magnus and the pectineus.

The branches to the *iliacus* consist of two to four filaments which arise in the abdomen, pass outward and enter the inner margin of the iliacus muscle.

The branch to the *psoas magnus* arises in the lower part of the iliac fossa and supplies the inferior portion of that muscle. It may originate in common with the nerve to the femoral artery.

The branch to the *pectineus* leaves the anterior crural beneath Poupart's ligament, passes inward posterior to the femoral vessels and enters the anterior surface of its muscle.

bb. The **nerve to the femoral artery** usually takes origin in the iliac fossa, but frequently arises higher, sometimes as a distinct branch from the third lumbar nerve. It accompanies the anterior crural as far as Poupart's ligament, leaving the parent trunk at the lateral margin of the femoral sheath. At the ligament it gives off fine twigs which ramify over the posterior part of the femoral vessels, and from them tiny filaments pass to the middle of the thigh. Other twigs are distributed to the deep femoral artery and from this group a fine terminal thread traverses the nutrient foramen of the femur, after supplying branches to the periosteum.

b. The **anterior or superficial division** is mainly cutaneous in distribution. It supplies sensory twigs to the anterior and mesial surfaces of the thigh and motor twigs to the sartorius.

Branches of this division are: (*aa*) the *middle cutaneous* and (*bb*) the *internal cutaneous*.

aa. The **middle cutaneous nerve** (rr. cutanei anteriores) (Fig. 1110) consists of two branches, an external and an internal, both of which contain motor as well as sensory fibres.

The *external branch* passes downward under the sartorius, to whose posterior surface are given off a row of fine twigs which enter the upper portion of the muscle. The continuation of the nerve pierces the sartorius at the junction of the upper and middle thirds, then pushes its way through the fascia lata and splits into fine filaments which supply the integument over the rectus femoris as far as the knee.

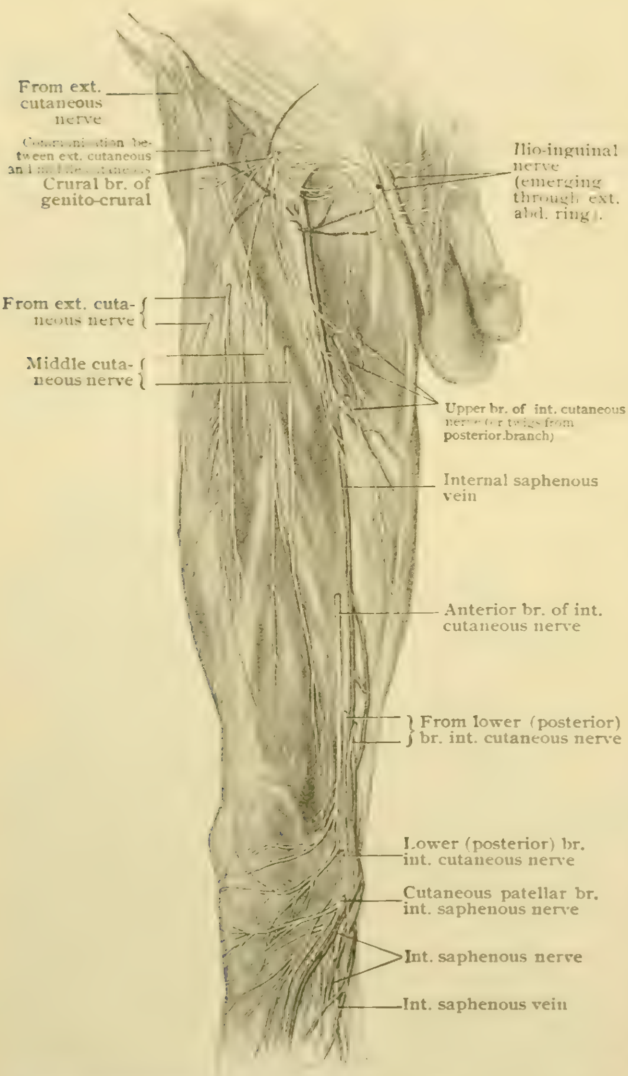
The *internal branch* is sometimes united in the upper part of its course with the external. It supplies twigs to the sartorius but seldom pierces that muscle, usually passing internal and anterior. This branch, like the external, is distributed to the anterior integument of the thigh as far down as the knee and frequently inosculates with the crural branch of the genito-crural.

Variations.—Sometimes the middle cutaneous arises from the beginning of the anterior crural or from the lumbar plexus and replaces in toto or in part the crural branch of the genito-crural.

bb. The **internal cutaneous nerve** (**rr. cutanei mediales**) leaves the anterior crural in the neighborhood of Poupart's ligament and descends in Scarpa's triangle, at the apex of which it crosses obliquely the femoral vessels to attain their mesial side. It passes superficial to or through the sartorius muscle and divides, either anterior or internal to the superficial femoral artery, into its **terminal branches**, the *anterior* and the *posterior* (Fig. 1110).

Two or three branches are given off by the main trunk. One of these pierces the fascia lata immediately below the saphenous opening and accompanies the internal saphenous vein down to the middle of the thigh, supplying the integument in its immediate vicinity. Another branch pierces the fascia lata at about the middle of the thigh and supplies the skin of the antero-median aspect as far down as the knee. These branches sometimes arise directly from the anterior crural, and not infrequently the nerve to the pectineus gives off a branch which forms a loop at the linner side of the femoral artery with a nerve which passes anterior to that vessel.

FIG. 1110.



Superficial dissection of right thigh, showing cutaneous nerves of inner anterior aspect; long saphenous vein is seen disappearing through saphenous opening.

The *anterior branch* pierces the fascia lata in the lower third of the thigh, descends in the neighborhood of the tendon of the adductor magnus and eventually passes across the patella to reach the lateral region of the knee. It supplies the skin in the vicinity of the adductor magnus tendon and inosculates at the knee with a branch of the internal saphenous nerve.

The *posterior branch* continues down beneath the posterior edge of the sartorius and becomes superficial by perforating the fascia lata at the mesial aspect of the knee. Its ultimate filaments supply the integument of the lower part of the inner side of the thigh and the upper portion of the leg. Before becoming superficial it inosculates below the middle of the thigh with the obturator and internal saphenous nerves to form the **subsartorial** or **obturator plexus** (Fig. 1109). At the knee and in the upper part of the leg it again forms connections with the internal saphenous nerve.

c. The **posterior** or **deep division** of the anterior crural nerve consists of a fasces of nerve-bundles which furnishes innervation to those muscles which comprise the quadriceps extensor femoris and terminates as the internal saphenous nerve.

Branches of this division are: (*aa*) the *muscular*, (*bb*) the *articular* and (*cc*) the *internal saphenous*.

aa. The **muscular branches** (**rr. musculares**) supply the rectus femoris, the vastus externus, the crureus, the subcrureus and the vastus internus.

The branch to the *rectus femoris* usually splits into three twigs, which separately enter the posterior surface of their muscle. It furnishes fine twigs to the antero-lateral portion of the capsule of the hip joint.

The branch to the *vastus externus* passes over the rectus and, in company with the descending branch of the external circumflex artery, reaches the vastus externus, whose anterior margin it enters in a series of twigs. It sends a branch down to the knee joint.

The nerves to the *crureus* number usually either two or three. The *upper branch* is usually the shortest and passes directly to the anterior surface of the crureus, where it penetrates the substance and supplies the upper portion of the muscle. A *second branch* pierces the vastus internus and passes downward under the anterior border of that muscle. It supplies the lower portion of the crureus, the subcrureus, the periosteum of the lower anterior part of the femur and the capsular ligament of the knee joint. A *third branch* is distributed to the lateral portion of the crureus and by means of its terminal filaments aids in the innervation of the knee joint.

FIG. 1111.

Dissection of right thigh, showing relation of anterior crural nerve to blood-vessels and to Hunter's canal.

The branch to the *vastus internus* accompanies the internal saphenous nerve along the inner side of the vastus internus, under cover of the strong aponeurosis which forms the roof of Hunter's canal. It sends filaments to the upper part of the vastus internus and then enters that muscle about the middle of the thigh. Its continuation accompanies the deep branch of the anastomotica magna artery and supplies the capsule of the knee joint.

bb. The **articular branches** (rr. articulares) supply the hip and knee joints. Those filaments which are destined for the hip are derivatives of the branch to the rectus femoris. Those which aid in the innervation of the knee arise from the internal saphenous and from the nerves to the vasti externus and internus and the crureus.

cc. The **internal** or **long saphenous nerve** (**n. saphenus**) (Fig. 1109) is the continuation of the posterior division of the anterior crural nerve. It courses down the thigh first lateral to and then anterior to the superficial femoral artery under cover of the sartorius muscle. At the apex of Scarpa's triangle it enters Hunter's canal and accompanies the vessels therein contained as far as the opening in the adductor magnus. Departing from the vessels at this point, the nerve, piercing the anterior wall of Hunter's canal, continues a downward course between the vastus

internus and the adductor magnus. At the inner side of the knee it becomes superficial by passing between the tendons of the sartorius and gracilis and by piercing the deep fascia in this situation. Thence it descends in the leg in association with the internal saphenous vein, at the ankle passing anterior to the internal malleolus and reaching the inner aspect of the foot, on which it extends only as far as the metacarpo-phalangeal articulation of the great toe (Fig. 1118).

Branches of the internal saphenous are: the *communicating*, the *infrapatellar*, the *articular* and the *terminal*.

The *communicating branch* arises beneath the sartorius at about the middle of the thigh and inosculates with filaments from the obturator and internal cutaneous nerves to form the *subsartorial* or *obturator plexus*.

The *infrapatellar branch* (r. infrapatellaris) (Fig. 1117) arises at the lower part of the thigh. It perforates the sartorius and the fascia lata and spreads out beneath the integument of the knee, where it inosculates with terminal filaments of the internal, the middle and sometimes the external cutaneous nerve to form the *patellar plexus* (Fig. 1117).

The *articular branch* (r. articularis) is an inconstant twig which supplies the inner portion of the capsule of the knee joint.

The *terminal branches* are distributed to the integument of the anterior internal portion of the leg and the posterior half of the dorsum and mesial side of the foot.

Practical Considerations.—All the branches of the lumbar plexus have motor and sensory fibres, both of which are affected in paralysis. The lesion is usually central, involving the spinal cord, as in tabes dorsalis, fracture of the spine or Pott's disease, and involves several nerves, or all of them below the seat of the lesion; the individual branches are not often affected.

The *ilio-hypogastric* may be divided by the incision in kidney operations or may be included in the sutures. This nerve and the *ilio-inguinal* are sometimes involved in operations in the inguinal region.

The *genito-crural* sends one branch through the inguinal canal to the cremaster muscle, and another under Poupart's ligament to the skin of the inner side of the thigh, just below the ligament. Gentle irritation of the skin here will cause retraction of the testicle (cremaster reflex), especially in children.

The *anterior crural* has been paralyzed by the pressure of tumors in the pelvis, has been involved in a psoas abscess, and has been injured in fracture of the pubic ramus and—rarely—in fractures of the femur. If the lesion involving the nerve is within the pelvis the paralysis would affect the ilio-psoas, quadriceps extensor femoris, sartorius and pectineus. If the lesion is outside the abdomen the ilio-psoas will escape. A complete paralysis would prevent flexion of the hip, or extension of the knee. The patient is then compelled to avoid flexion of the knee in walking. There will be anesthesia in the parts supplied by the middle and internal cutaneous, and long saphenous nerves, that is, in the thigh along the anterior and inner surface (middle and internal cutaneous), except in the upper third (crural branch of the genito-crural), and along the inner surface of the leg and inner border of the foot to the ball of the big toe (long saphenous). The long saphenous vein and nerve lie close together, about a finger's breadth behind the inner border of the tibia. In the thigh, while they have the same general direction, the vein lies in the superficial fascia, the nerve under the deep fascia. The nerve in the thigh is, therefore, not so liable to injury as is the vein.

Since the anterior crural breaks up into numerous branches just below Poupart's ligament, its trunk in the thigh is very short. It lies slightly external to the femoral artery and can be exposed by an incision extending downward from the middle of Poupart's ligament.

Paralysis of the *obturator nerve* would interfere with adduction of the thigh as well as with internal and external rotation. It may be caused by pressure within the pelvis, as by the child's head in difficult labor, by a tumor or by an obturator hernia. Paralysis of the obturator is usually found in conjunction with paralysis of the anterior crural. The nerve may be irritated in coxalgia, in sacro-iliac disease, and on the left side in carcinoma or fæcal impaction in the sigmoid flexure. On account of its terminal distribution pain in the knee is usually complained of whenever this nerve or one of its branches is involved.

THE SACRAL PLEXUS.

The sacral or sciatic plexus (**plexus sacralis**) (Fig. 1112) is formed by a portion of the fourth lumbar nerve, all of the fifth lumbar, the entire first sacral and parts of the second and third sacral nerves. As previously stated (page 1320) the fourth lumbar nerve or *n. furcalis* splits into two portions, a larger upper and a smaller lower, the former contributing to the lumbar plexus and the latter uniting with the fifth lumbar nerve. The lower portion of the fourth lumbar having passed downward behind the internal iliac vessels, divides into anterior and posterior branches, which fuse respectively with similar branches of the fifth lumbar, the two trunks thus formed comprising the **lumbo-sacral cord** (**truncus lumbosacralis**). This double structure emerges from the mesial margin of the psoas magnus, passes down over the brim of the pelvis and constitutes the lumbar contribution to the sacral plexus. The first and second sacral nerves leave their foramina, pass laterally, anterior to the pyriformis, and split into anterior and posterior branches. The third sacral nerve or *n. bigeminus* divides, not into anterior and posterior branches, but into upper and lower, the upper becoming a constituent of the sacral and the lower a portion of the pudendal plexus. Converging toward the lower portion of the great sacro-sciatic foramen, the posterior portion of the lumbo-sacral cord and the posterior branches of the first and second sacral nerves fuse and form the *external popliteal* or *peroneal* and some minor *posterior* nerves. The anterior portion of the lumbo-sacral cord, the anterior branches of the first and second sacral nerves and the upper part of the third sacral unite in the *internal popliteal* or *tibial* nerve and some small *anterior* branches (Fig. 1112). The resulting composite structure, the sacral plexus, is a broad triangular felt-work of nerve-strands, whose base points toward the sacrum and whose apex presents at the great sacro-sciatic foramen. The plexus is an occupant of the pelvis, on whose posterior wall it is situated, lying upon the pyriformis muscle and under cover of the parietal portion of the pelvic fascia. In relation with it anteriorly are the ureter, the pelvic colon and the internal iliac artery and vein. The ilio-lumbar vessels pass above the lumbo-sacral cord and between the cord and the first sacral nerve are found the superior gluteal vessels. The interval between the second and third sacral nerves is occupied by the sciatic artery and vein.

Fig. 1112.

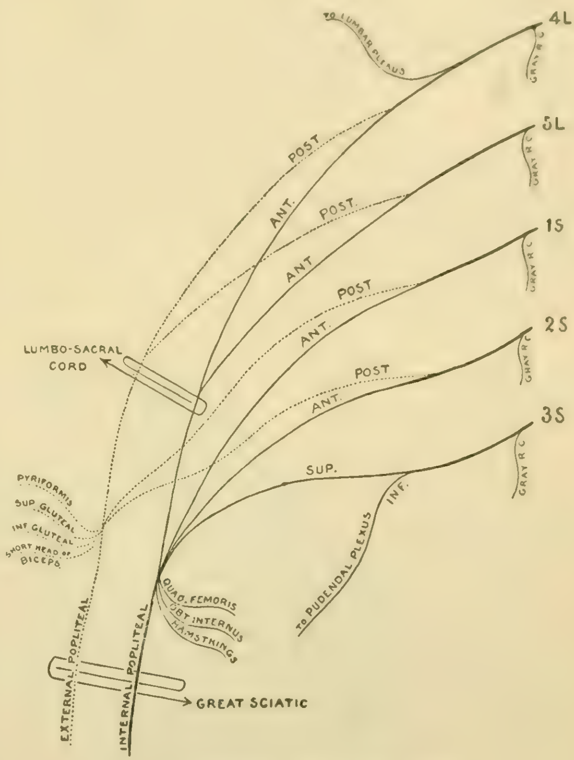


Diagram illustrating plan of sacral plexus.

In size the roots of the sacral plexus vary considerably, the largest, the fifth lumbar nerve, measuring about 7 mm. in diameter and the smallest, the third sacral, 3.5 mm. As regards length, the contribution from the fourth lumbar has the longest course and that from the third sacral the shortest.

Branches.—The branches of the sacral plexus and their classification centre around the great sciatic nerve and its distribution. This nerve comprises two

essential and frequently independent elements, the internal popliteal or tibial and the external popliteal or peroneal. Typically the sciatic divides into these two nerves in the lower part of the thigh; very often, however, they are distinct from the outset, arising independently from the plexus, being separated in the great sacro-sciatic foramen by the inferior fibres of the pyriformis muscle and passing through the thigh as contiguous but ununited structures. Moreover, even when the sciatic appears to be a single cord, dissection will reveal its duality in origin and course. The branches of the sacral plexus may be grouped as follows :—

I. Collateral Branches.
- A. Anterior branches :
  - 1. Muscular
  - 2. Articular
- B. Posterior branches :
  - 3. Muscular
  - 4. Articular

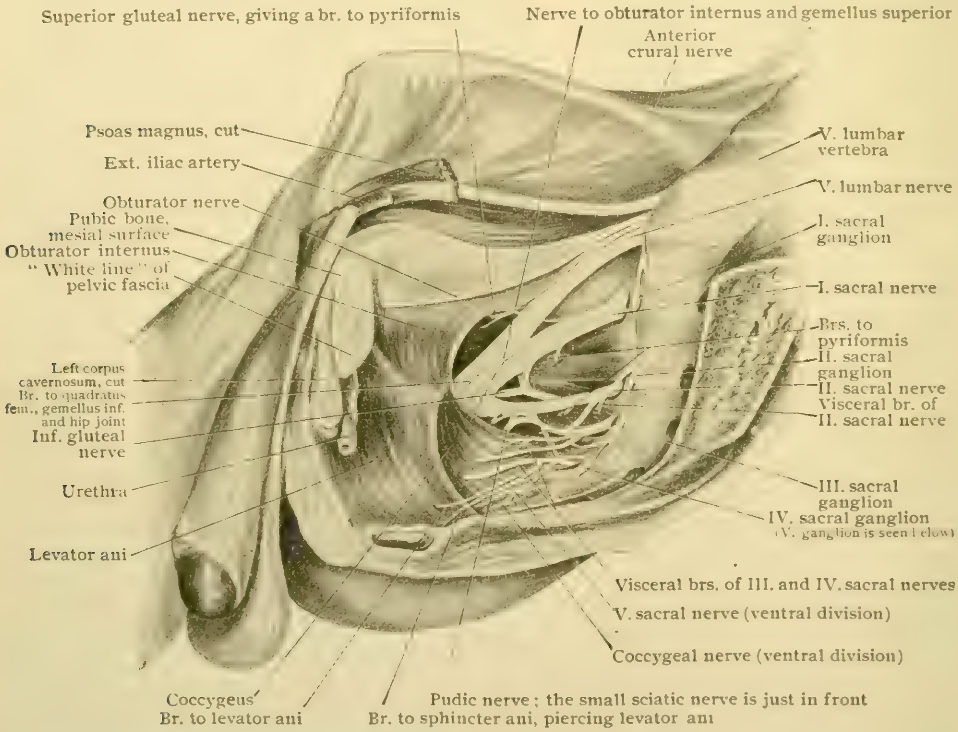
II. Terminal Branches.
- A. Anterior branch:
  - 5. External popliteal
- B. Posterior branch:
  - 6. Internal popliteal

COLLATERAL BRANCHES.

The **collateral branches** comprise two sets, designated according to the portion of the plexus from which they arise as the *anterior* and the *posterior*.

The **anterior collateral branches** include : (1) the *muscular branches* and (2) the *articular branches.*

FIG. 1113.



Dissection of right half of pelvis, showing sacral and pudendal plexuses; section is not mesial, but to left of mid-line.

1. The **muscular branches** supply (*a*) the quadratus femoris, (*b*) the obturator internus, the gemelli and (*c*) the hamstring muscles and the adductor magnus.

a. The **nerve to the quadratus femoris** arises from the anterior surface of the upper portion of the plexus, its fibres coming from the fourth and fifth lumbar and first sacral nerves. It is frequently united in the first part of its course with the nerve to the obturator internus. Having traversed the great sacro-sciatic foramen it courses downward anterior to the great sciatic nerve,

the obturator internus and the gemelli and posterior to the capsular ligament of the hip. Reaching the upper margin of the quadratus femoris it passes anterior to that muscle and terminates in fibres which enter the anterior surface of the muscle for which it is destined. In addition to supplying the quadratus femoris it sends twigs to the *gemellus inferior* and to the hip joint.

Variations.—The nerve to the quadratus femoris may supply the upper portion of the adductor magnus and may send filaments to the superior gemellus, either as an additional or as a sole supply.

b. The **nerve to the obturator internus** has an origin one step lower than that of the preceding nerve, with which it is frequently associated for a short distance. It arises from the anterior aspect of the fifth lumbar and first and second sacral nerves and leaves the pelvis through the great sacro-sciatic foramen, below the pyriformis and the great sciatic nerve and lateral to the pudic nerve and vessels (Fig. 1114). Crossing the spine of the ischium it courses anteriorly through the lesser sacro-sciatic foramen and enters the ischio-rectal fossa, where it terminates by splitting into filaments which enter the posterior surface of the obturator internus. A small branch of this nerve supplies the *gemellus superior.*

c. The **nerve to the hamstring muscles** consists of a bundle of fibres which forms the mesial edge of the gluteal portion of the sciatic nerve. Arising from the anterior aspect of the plexus and deriving its fibres from the fourth and fifth lumbar and first, second and third sacral nerves, it descends in close connection with the sciatic, lying first anterior to the latter and then to the inner side (Fig. 1115). In the thigh the nerve breaks up into two sets of fibres, an *upper* and a *lower.* The **upper set** leaves the sciatic below the tuber ischii and sends fibres to the upper portion of the *semitendinosus* and the long head of the *biceps femoris.* The **lower set** arises further down in the thigh and funishes twigs to the *semimembranosus*, the *adductor magnus* and the lower part of the *semitendinosus.*

2. The **articular branches** are derived from the nerve to the quadratus femoris and sometimes from the anterior aspect of the sciatic. After descending between the capsule of the hip and the gemelli they supply the posterior portion of the capsular ligament of the hip joint.

The **posterior collateral branches** comprise, like the anterior, (3) the *muscular* and (4) the *articular branches.*

3. The **muscular branches** include (*a*) the nerve to the pyriformis, (*b*) the superior and (*c*) the inferior gluteal nerves and (*d*) the nerve to the short head of the biceps.

a. The **nerve to the pyriformis** may be either single or double. It arises from the dorsal aspect of the second or first and second sacral nerves and enters the anterior surface of its muscle. There may be an additional filament from the root to the superior gluteal nerve contributed by the first sacral nerve.

b. The **superior gluteal nerve (n. glutaeus superior)** (Fig. 1114) arises by three roots from the dorsal surface of the posterior portion of the lumbo-sacral cord and the first sacral nerve, its fibres being derivatives of the fourth and fifth lumbar and first sacral nerves. After passing above the pyriformis muscle in company with the superior gluteal artery and vein, it leaves the pelvis through the great sacro-sciatic foramen and divides into (*aa*) a *superior* and (*bb*) an *inferior branch.*

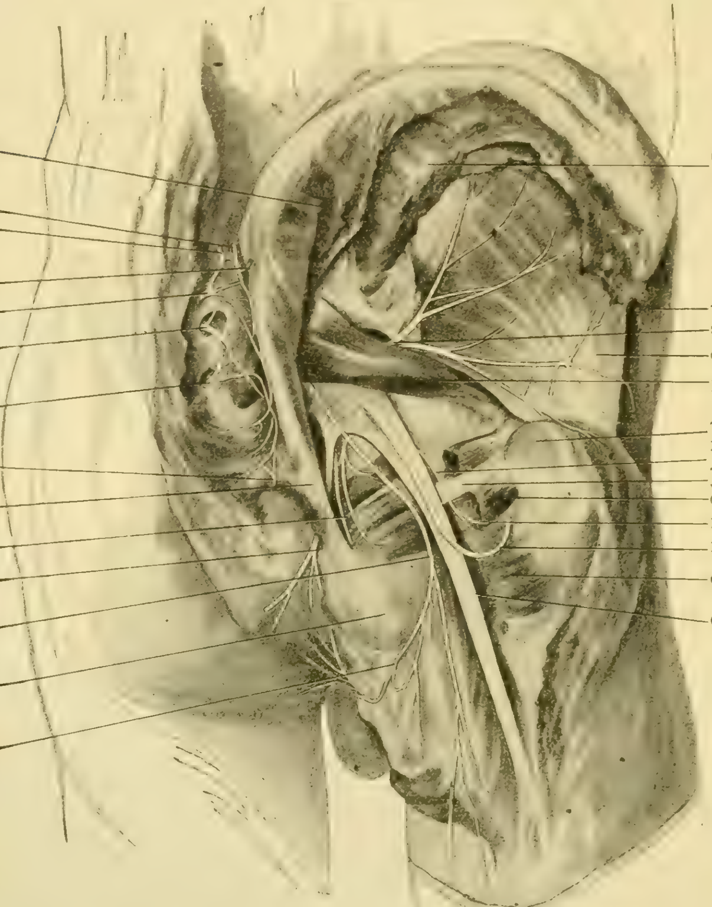
aa. The **superior branch** (Fig. 1114) is the smaller of the two, and after passing beneath the gluteus medius and along the upper margin of the gluteus minimus reaches and enters the middle of the inner surface of the former muscle, of which it is only the partial nerve supply.

bb. The **inferior branch**, larger than the superior, is the continuation of the main trunk. After a forward course between the glutei medius and minimus in company with the lower branch of the deep portion of the superior gluteal artery, it reaches the under surface of the tensor fasciæ femoris (Fig. 1114). It supplies the glutei medius and minimus and its terminal fibres constitute the supply of the tensor fasciæ femoris.

c. The **inferior gluteal nerve (n. glutaeus inferior)** (Fig. 1114) is formed by twigs which arise from the dorsal surface of the posterior part of the lumbo-sacral cord and the first, and sometimes the second, sacral nerve. It is frequently fused in the early part of its course with the small sciatic nerve and not infrequently with the nerve to the short head of the biceps. It usually sends a small branch down to join the small sciatic nerve. Passing beneath the pyriformis it emerges from the pelvis into the gluteal region through the great sacro-sciatic foramen, superficial to the great sciatic nerve. Immediately upon entering the buttock it breaks up fan-wise into a number of twigs which enter the deep surface of the gluteus maximus about midway between the origin and insertion.

d. The **nerve to the short head of the biceps** (Fig. 1115) apparently arises from the lateral margin of the upper part of the great sciatic nerve. The fibres comprising it can be traced back to the fifth lumbar and first and second sacral nerves, sometimes in combination with the roots of the inferior gluteal nerve. Leaving the great sciatic in the middle of the thigh, often as a common trunk with the articular branch, it enters the substance of the short head of the biceps.

FIG. 1114.



Deep dissection of right buttock, showing emergence of great sciatic nerve below pyriformis muscle; also muscular branches and posterior divisions of sacral nerves.

4. The **articular branches** supply the knee and are usually two in number. The **upper** arises either in common with the nerve to the short head of the biceps or independently from the lateral portion of the great sciatic. Descending on the posterior surface of the femoral head of the biceps it passes between the external condyle of the femur and the tendon of the biceps and supplies the lateral portion of the capsular ligament of the knee. The **lower** arises from the external popliteal nerve in the upper portion of the popliteal space and divides into two portions which supply the lateral and posterior portions of the capsular ligament of the knee. From the branch to the posterior part of the capsule is given off a tiny thread to the superior tibio-fibular articulation.

TERMINAL BRANCHES.

The terminal branches of the sacral plexus are the *external* and the *internal popliteal*, and these are usually fused in the upper part of their course into the *great sciatic nerve.*

THE GREAT SCIATIC NERVE.

The great sciatic nerve (n. ischiadicus), the largest nerve of the entire human body, is a thick bundle of nerve-fibres derived from both the anterior and posterior portions of

FIG. 1115.

Deep dissection of posterior surface of right thigh, showing great sciatic nerve dividing into external popliteal (peroneal) and internal popliteal (tibial) nerves.

the sacral plexus (Fig. 1112). Properly it consists of two elements only, the **external** and **internal popliteal nerves,** the former from the posterior and the latter

from the anterior portion of the plexus, its constituent fibres being derivatives of all of the spinal nerves contributing to the sacral plexus. Bound up with it and apparently integral portions of it, are the nerve to the hamstring muscles and the nerve to the short head of the biceps. From within outward, the four components are arranged in the following order: the nerve to the hamstrings, the internal popliteal nerve, the external popliteal nerve and the nerve to the short head of the biceps.

Arising from the apex of the sacral plexus and proceeding as its direct continuation, the great sciatic leaves the pelvis through the greater sacro-sciatic foramen below the pyriformis muscle and above the gemellus superior. In the form of a thick flat trunk, about 1.5 cm. wide, it turns downward and lies anterior to the gluteus maximus and posterior to successively the gemellus superior, the tendon of the obturator internus, the gemellus inferior, the quadratus femoris and the upper portion of the adductor magnus, being accompanied in the upper part of its course by the sciatic artery and the arteria comes nervi ischiadici. Lying external to the nerve is the great trochanter and internal to it is the tuberosity of the ischium (Fig. 1115). Entering the thigh by emerging from beneath the gluteus maximus, the nerve lies under cover of the hamstrings and at a varying position in the thigh it splits into its terminal divisions: (5) the *external popliteal* and (6) the *internal popliteal*. As previously stated (page 1332), these nerves may be separate from their origin.

5. The External Popliteal Nerve.

The external popliteal or **peroneal nerve** (**n. peronaeus communis**) (Fig. 1115) is homologous with the musculo-spiral of the upper extremity. It comprises fibres derived from the posterior portions of the fourth and fifth lumbar and first and second sacral nerves. As a part of the great sciatic, it follows the course in the thigh just described and after the bifurcation of the sciatic enters the popliteal space as an independent nerve. In the upper part of the popliteal space it lies beneath the biceps and later inclines gradually outward between the tendon of the biceps and the outer head of the gastrocnemius. Passing over the latter, it reaches the under surface of the deep fascia posterior to the head of the fibula, 2–3 cm. below which it divides into its terminal branches.

Branches of the external popliteal nerve are: the *cutaneous* and the *terminal*.

The **cutaneous branches** are: (*a*) the *sural* and (*b*) the *peroneal communicating*.

a. The **sural branch** (**n. cutaneus surae lateralis**) (Fig. 1119) consists of one or more, usually two, filaments which arise in the popliteal space, frequently in common with the peroneal communicating nerve. Becoming superficial by piercing the deep fascia overlying the outer head of the gastrocnemius, it is distributed to the integument of the upper two thirds of the lateral aspect of the leg. Its degree of development is in inverse ratio to that of the small sciatic and short saphenous nerves.

b. The **peroneal communicating nerve** (**r. anastomoticus peronaeus**) (Fig. 1119), also called the *n. communicans fibularis*, is larger than the preceding. Leaving the peroneal in the popliteal space, often in combination with the sural nerve or nerves, it descends beneath the deep fascia and over the lateral head of the gastrocnemius to the middle of the leg. Here it is usually joined by the tibial communicating branch from the internal popliteal and the joint trunk so formed (Fig. 1125) is called the **external** or **short saphenous nerve** (page 1342).

The **terminal branches** comprise: (*a*) the *recurrent articular*, (*b*) the *anterior tibial* and (*c*) the *musculo-cutaneous*.

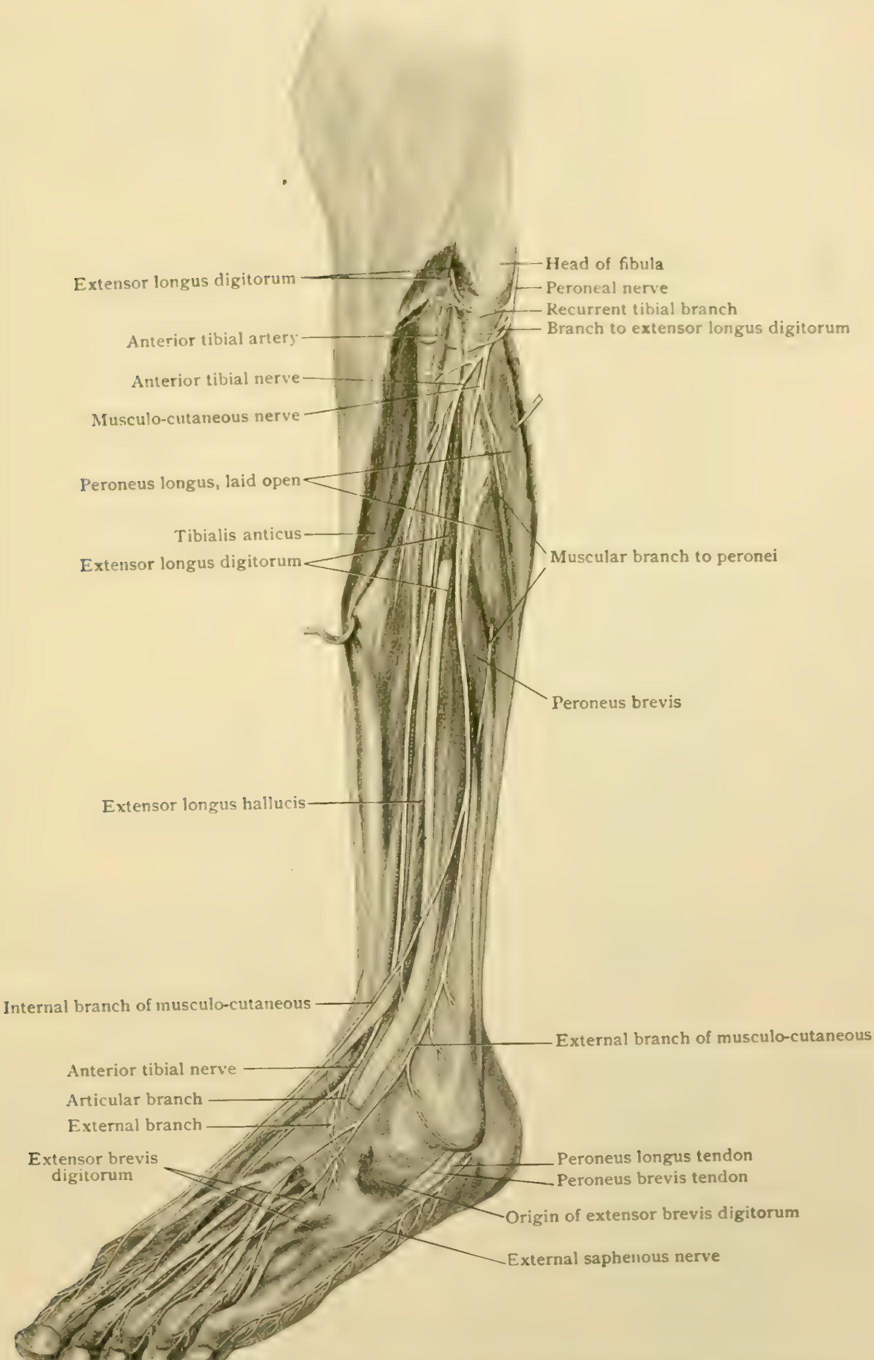
a. The **recurrent articular** or **recurrent tibial branch** (Fig. 1116) is the smallest of the three. Given off a short distance below the head of the fibula it passes forward under the peroneus longus and the extensor longus digitorum, courses upward in the musculature of the tibialis anticus and divides into filaments which supply the upper fibres of the tibialis anticus, the anterior portion of the knee joint, the superior tibio-fibular articulation and the periosteum of the external tuberosity of the tibia.

b. The Anterior Tibial Nerve.

The anterior tibial nerve (**n. peronaeus profundus**) originates below the head of the fibula in the interval between the peroneus longus and the fibula. After winding

externally around the head of the fibula beneath the peroneus longus, the extensor proprius hallucis and the extensor longus digitorum it reaches the anterior aspect of

FIG. 1116.



Dissection of antero-lateral surface of left leg and of dorsum of foot, showing anterior tibial and musculo-cutaneous nerves.

the leg. Lying on the anterior surface of the interosseous membrane it joins the anterior tibial vessels 8–12 cm. below its origin and accompanies these vessels

down the front of the leg as far as the ankle, lying first to their outer side, then anterior to them and at the ankle to the outer side again (Fig. 1116).

Branches of the anterior tibial nerve are : (*aa*) the *muscular*, (*bb*) the *articular*, (*cc*) the *external* and (*dd*) *internal terminal*.

aa. The **muscular branches** are distributed to the tibialis anticus, the extensor longus digitorum, the extensor proprius hallucis and the peroneus tertius.

The nerves to the *tibialis anticus* consist of two twigs, an upper and a lower. The upper arises at the origin of the anterior tibial, passes beneath the peroneus longus and the extensor longus digitorum and enters the upper portion of the muscle. The lower arises in the interval between the tibialis anticus and the extensor longus digitorum and passes obliquely downward into the substance of the tibialis anticus.

The nerve to the *extensor longus digitorum* arises immediately below the preceding and enters the inner surface of the muscle which it supplies.

The nerves to the *extensor proprius hallucis*, usually two in number, arise in the middle of the leg and enter the substance of their muscle.

The nerve to the *peroneus tertius* is usually derived from the nerve to the extensor longus digitorum.

bb. The **articular branch** leaves the anterior tibial above the anterior annular ligament and is distributed to the forepart of the ankle-joint.

cc. The **internal terminal branch** (Fig. 1117) courses forward in the foot under the inner tendon of the extensor brevis digitorum and lateral to the dorsalis pedis artery, and reaches the base of the first digital cleft. Here it splits into two branches (**nn. digitales dorsales hallucis lateralis et digiti secundi medialis**), which supply the contiguous sides of the great and second toes and inosculate with branches of the musculo-cutaneous nerve. In the region of the tarsus it sends off the *first dorsal interosseous nerve*, which supplies the first dorsal interosseous muscle, the mesial metacarpal articulations and the first and second metacarpo-phalangeal joints. Like the other interosseous nerves, it sends a filament between the heads of its dorsal interosseous muscle for the supply of the adjacent articulations (Ruge).

dd. The **external terminal branch** (Fig. 1118) passes laterally over the tarsus under cover of the extensor brevis digitorum, to which muscle it sends branches. From it are given off two to four, usually three, *dorsal interosseous branches*, which decrease in size from within outward, the fourth often being lacking and the third quite rudimentary. These interosseous nerves are distributed to the adjacent articulations and sometimes to the second and third dorsal interosseous muscles. The fibres from the anterior tibial to the dorsal interosseous muscles are usually not their sole supply, the external plantar supplying constant branches for their innervation. From the latter are probably derived the motor innervation and from the occasional anterior tibial branches some extra sensory filaments. This branch usually ends in a gangliform enlargement, from which its branches are distributed.

Variations.—The anterior tibial sometimes supplies the mesial side of the great toe or the adjacent sides of the second and third toes. In one case the anterior tibial supplied the outer three and one-half toes, the inner toe and one-half being innervated by the musculo-cutaneous nerve. Rarely the anterior tibial has no digital distribution whatsoever.

c. The Musculo-Cutaneous Nerve.

The musculo-cutaneous nerve (**n. peronaeus superficialis**) (Fig. 1116) continues the course and direction of the external popliteal. Descending through the leg in a fascial tube in the septum between the peroneal muscles and the extensor longus digitorum it becomes superficial by piercing the deep fascia anterior to the fibula in the lower third of the leg. It may make its superficial appearance as a single nerve or as two branches.

Branches of the musculo-cutaneous are: (*aa*) the *muscular*, (*bb*) the *internal* and (*cc*) the *external terminal*.

aa. The **muscular branches (rr. musculares)** are destined for the peronei longus and brevis.

The nerves to the *peroneus longus* are two in number, an upper and a lower. They are given off at the upper and lower portions respectively of the fascial canal occupied by the parent nerve and enter the mesial surface of their muscle.

The nerve to the *peroneus brevis* arises with the lower branch to the peroneus longus and enters the musculature of the peroneus brevis.

bb. The **internal terminal branch** (**n. cutaneus dorsalis medialis**) (Fig. 1117), larger than the external, passes obliquely inward in front of the ankle and then forward over the dorsum of the foot. Cutaneous twigs are distributed to the anterior aspect of the lower third of the leg and the dorsum of the foot. Just below the anterior annular ligament the nerve breaks up into an *inner*, a *middle* and an *outer* branch.

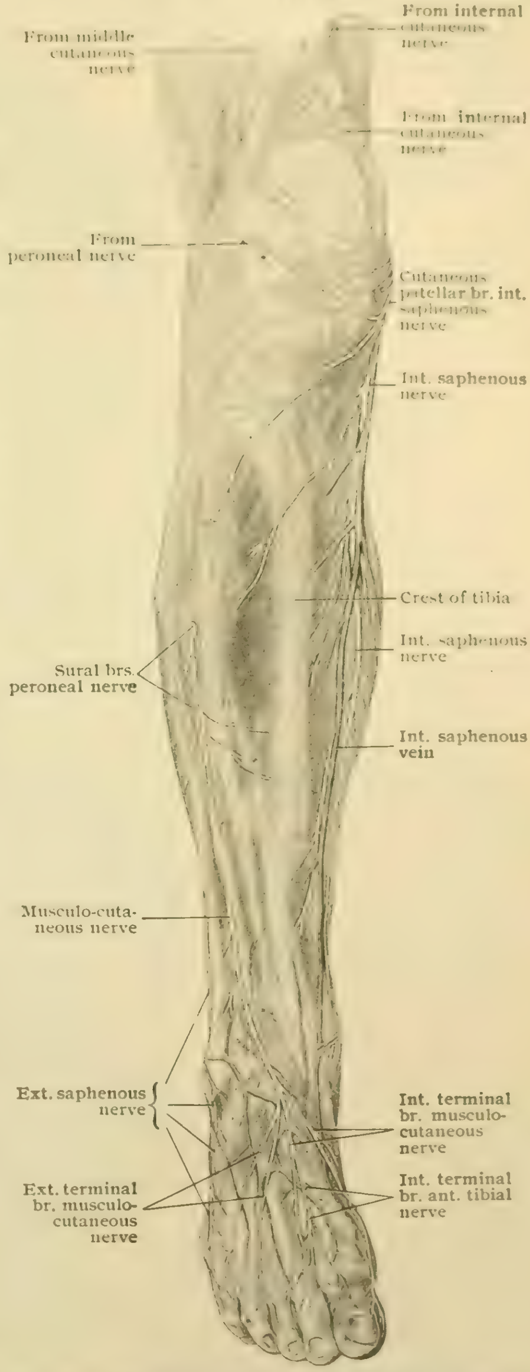
The *inner branch* inosculates with the internal saphenous nerve, from which it receives an accession of fibres, and passes forward to supply the integument of the mesial aspect of the foot and great toe. The *middle branch* follows the first metatarsal space and inosculates with the inner branch of the anterior tibial nerve. The *outer branch* courses down the second metatarsal space and divides into the two dorsal digital nerves (**nn. digitales dorsales pedis**) which supply the contiguous sides of the second and third toes. This branch is sometimes derived from the external terminal part of the musculo-cutaneous.

cc. The **external terminal branch** (**n. cutaneus dorsalis intermedius**) (Fig. 1117) courses down the leg anterior to the ankle and lateral to the inner branch, giving off twigs to the antero-lateral portion of the integument of the lower part of the leg and dorsum of the foot. Having reached the foot it breaks up into *inner* and *outer* branches.

The *inner branch* divides into dorsal digital branches for the supply of the adjacent sides of the third and fourth toes, and the *outer branch*, after receiving an accession of fibres through inosculation with the external saphenous, divides similarly into twigs for the contiguous sides of the fourth and fifth toes. The dorso-lateral aspects of the terminal phalanges and the nails receive additional filaments from the plantar nerves.

Variations.—Deficiencies in the internal branch are usually supplied by the anterior tibial nerve and in the external by the short saphenous. In case the external branch ends at the dorsum of the foot, the external saphenous, which would fill the vacancy at the digits, has its root from the external popliteal more strongly developed than usual, and thus the toes are supplied in an unusual manner but still by fibres from the external popliteal nerve.

FIG. 1117.



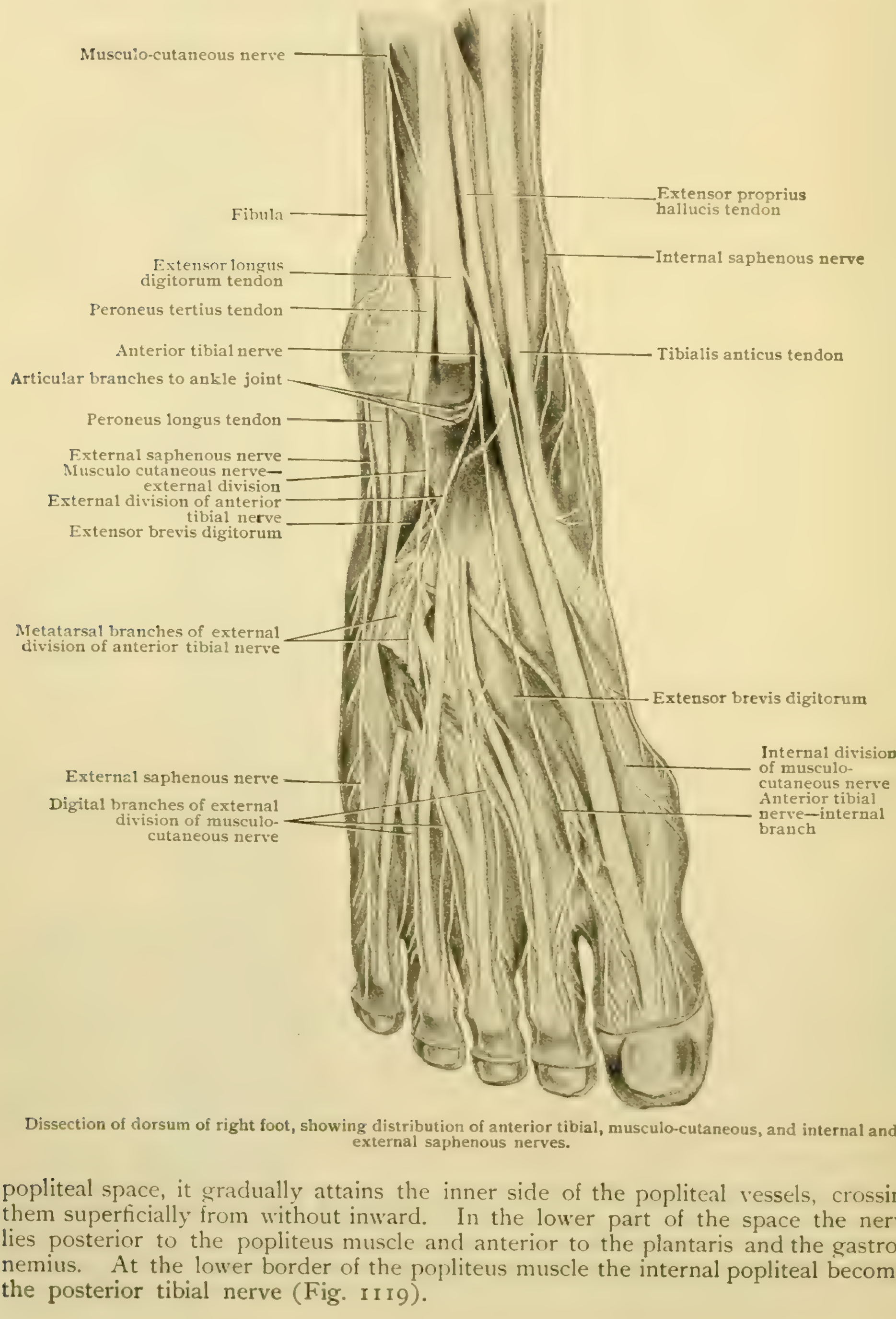
Superficial dissection of right leg and foot, showing cutaneous nerves of anterior surface.

6. The Internal Popliteal Nerve.

The internal popliteal or **tibial nerve** (**n. tibialis**) (Fig. 1115) is of greater size than the external and corresponds in its distribution to the combined median and ulnar nerves of the arm. Arising from the anterior portion of the sacral plexus, it includes fibres derived from the fourth and fifth lumbar

and first, second and third sacral nerves. Leaving the pelvis through the greater sacro-sciatic foramen below the pyriformis, and passing through the gluteal region and upper part of the thigh as the inner portion of the great sciatic nerve, it becomes an independent trunk at the point of bifurcation of the sciatic. Emerging from beneath the hamstring muscles and descending vertically through the middle of the

FIG. 1118.

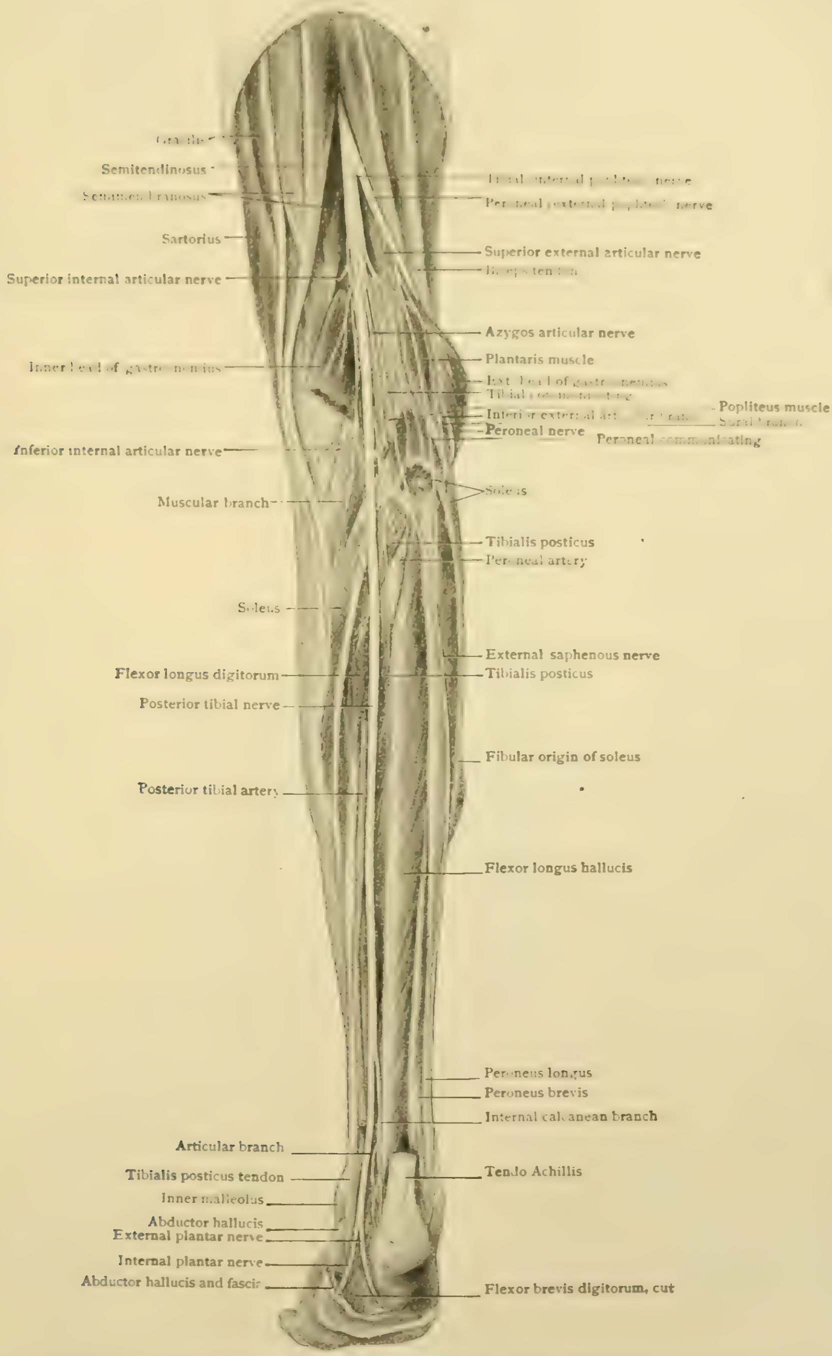


Dissection of dorsum of right foot, showing distribution of anterior tibial, musculo-cutaneous, and internal and external saphenous nerves.

popliteal space, it gradually attains the inner side of the popliteal vessels, crossing them superficially from without inward. In the lower part of the space the nerve lies posterior to the popliteus muscle and anterior to the plantaris and the gastrocnemius. At the lower border of the popliteus muscle the internal popliteal becomes the posterior tibial nerve (Fig. 1119).

Branches of the internal popliteal are: (*a*) the *articular*, (*b*) the *muscular*, (*c*) the *cutaneous* and (*d*) the *posterior tibial.*

FIG. 1119.



Dissection of the posterior surface of right leg, showing posterior tibial nerve and its branches and part of peroneal nerve.

a. The **articular branches** (rr. articulares) supply the hip and knee joints. The one destined for the hip has been described on page 1333. The branches to the knee are of

small size and of varying number. There are usually two, an *upper* and a *lower*, and these break up into small filaments which inosculate with the lower articular fibres of the external popliteal, forming the *popliteal plexus* of Rudinger. The *upper* or *azygos branch* usually pierces the posterior ligament of the joint, while the *lower* accompanies the inferior internal articular artery. When a *third* is present it accompanies the superior internal articular artery. From the popliteal plexus a number of fine filaments are furnished to the posterior portion of the knee joint and an occasional twig enters the popliteus muscle by piercing its posterior surface.

b. The **muscular branches** (**rr. musculares**) comprise two sets, those given off from the part above the division of the sciatic nerve and those given off below. The former have been described on page 1333. The latter consist of a series of five twigs which innervate the gastrocnemius, the soleus, the plantaris and the popliteus.

The nerves to the *gastrocnemius*, *soleus* and *plantaris* consist of two stout nerve trunks, an *upper* and a *lower*. The *upper* arises in the middle of the popliteal space and enters the lateral aspect of the inner head of the gastrocnemius. The *lower* arises a short distance below the upper and, frequently combined with the nerve to the plantaris, divides into two branches, a shorter for the outer head of the gastrocnemius, and a longer, which enters the superior border of the soleus, the upper part of which muscle it supplies. From the nerve to the plantaris is furnished a filament to the knee joint.

The nerve to the *popliteus* is a complex structure, with a distribution much wider than is implied in its name. After reaching the lower margin of the popliteus muscle the nerve turns forward, ascends between the anterior aspect of the muscle and the tibia, and enters the anterior surface of the popliteus. A branch supplies the periosteum of the tibia and then enters the nutrient foramen of that bone. Another, the *interosseous branch* (**n. interosseus cruris**) courses first posterior to and then between the layers of the interosseous membrane almost to its lower margin. Terminal fibres are distributed to the periosteum of the tibia and to the inferior tibio-fibular articulation. Other filaments reach the tibialis posticus muscle and the superior tibio-fibular articulation.

c. The **cutaneous branch** is the *tibial communicating nerve.*

The **tibial communicating nerve** or *n. tibialis communicans* (**n. cutaneus surae medialis**) (Fig. 1119) arises in the upper portion of the popliteal space, through which it passes, posterior to the internal popliteal nerve, to the fissure between the heads of the gastrocnemius. In company with the external saphenous vein, the nerve descends in this interval to the tendo Achillis and, after piercing the deep fascia at about the middle of the leg, is joined by the peroneal communicating nerve, the fusion resulting in the **external or short saphenous nerve** (**n. suralis**). This joint nerve (Fig. 1119) courses down the postero-lateral aspect of the lower part of the leg, passes posterior to and beneath the external malleolus in company with the external saphenous vein and follows a course obliquely downward and forward along the lateral margin of the foot to the dorsal aspect of the outer side of the fifth toe, at the far end of whose distal phalanx the nerve terminates. In its course through the leg and foot it supplies sensory twigs to the postero-lateral part of the lower third of the leg, the region over the external malleolus, the lateral portion of the heel (**rr. calcanei laterales**), the dorso-lateral portion of the foot (**n. cutaneus dorsalis lateralis**) and the outer half of the dorsum of the fifth toe. Twigs are furnished to the ankle, and to the astragalo-calcanean and possibly other intertarsal articulations. In the foot it communicates with the anterior tibial nerve.

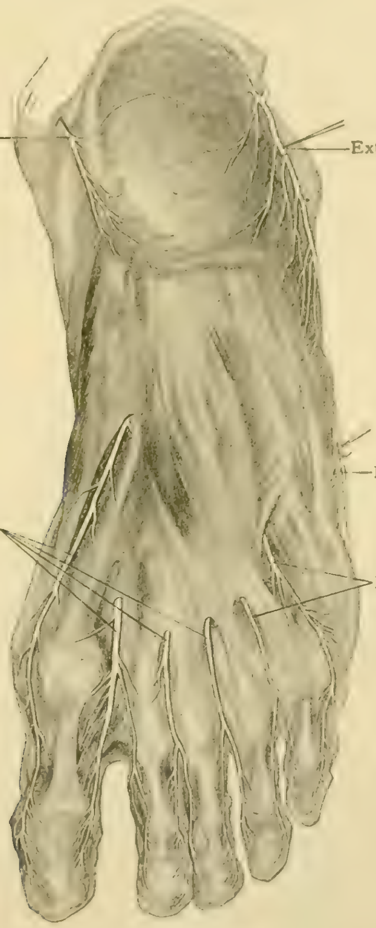
Variations.—The point of union of the two tributaries of the external saphenous is subject to wide variations, sometimes being high in the popliteal space and sometimes there being no union at all, in the latter instance the nerve which reaches and supplies the foot usually being the n. communicans tibialis. In one specimen found in the anatomical rooms of the University of Pennsylvania the great sciatic nerve divided just below the margin of the gluteus maximus. The n. communicans fibularis arose in the middle of the thigh and the n. communicans tibialis in the popliteal space. Union took place 3 cm. below the origin of the n. communicans tibialis, the n. communicans fibularis sending a few fibres across to the internal popliteal nerve before entering the external saphenous. In another cadaver in the same laboratory the two tributaries arose 3 cm. apart from each other about 10 cm. above the knee, the n. communicans tibialis arising the higher and piercing the inner head of the gastrocnemius before joining the n. communicans fibularis. Variations in distribution may occur, the nerve sometimes supplying the dorsal aspect of two and one-half digits, under such circumstances the n. communicans fibularis usually being of increased size. The nerve may terminate in the foot and not have any digital distribution.

d. THE POSTERIOR TIBIAL NERVE.

The **posterior tibial nerve** (**n. tibialis**) (Fig. 1119) is the direct continuation of the internal popliteal and begins at the lower border of the popliteus muscle. It extends downward, in a sheath shared by the posterior tibial vessels, between the superficial and deep muscles of the posterior portion of the leg. Anterior to it are

the tibia and the deep leg muscles and posteriorly lie the soleus and gastrocnemius in the upper part of the leg. Above the ankle the nerve becomes superficial, and is covered only by integument and the fasciæ. Owing to the inward inclination of the posterior tibial vessels the nerve, while pursuing a straight course, changes its relative position to the vessels, in the upper part of the leg lying to the inner side, lower down behind and above the ankle attaining the outer aspect of the vessels (Fig. 1121). Passing posterior to and then below the internal malleolus, the posterior tibial nerve divides, under cover of the internal annular ligament, into its terminal branches, the internal and the external plantar.

FIG. 1120.



Superficial dissection of right foot, showing cutaneous nerves on plantar surface.

Branches of the posterior tibial nerve are: (*aa*) the *muscular*, (*bb*) the *internal calcanean*, (*cc*) the *articular*, (*dd*) the *internal plantar* and (*ee*) the *external plantar.*

aa. The **muscular branches** (rr. musculares) supply the tibialis posticus, the soleus, the flexor longus hallucis and the flexor longus digitorum.

The nerve to the *tibialis posticus* supplies that muscle and sends a branch to the flexor longus digitorum and one to the lower part of the soleus. At the posterior aspect of the tibialis posticus it gives off a long slender branch which accompanies the peroneal artery nearly to the ankle, supplying twigs to the artery, to the periosteum of the fibula and a branch which enters the nutrient canal of the fibula.

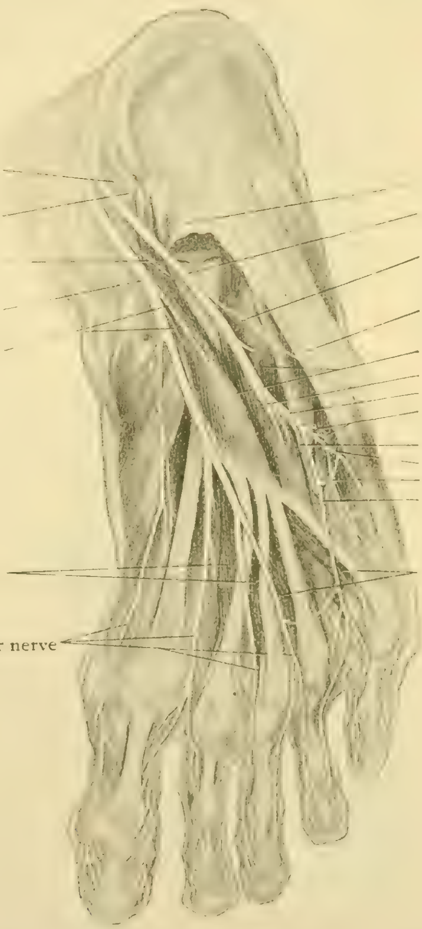
The nerves to the *flexores longus hallucis* and *longus digitorum* leave the posterior tibial about the middle of the leg and pass directly to their muscles.

bb. The **internal calcanean nerve** (**rr. calcanei mediales**) arises from the posterior tibial at the lower part of the leg and becomes superficial by traversing an opening in the internal annular ligament. Dividing into two sets of twigs, **internal calcanean** and **calcaneo-plantar**, it is distributed to the integument of the internal aspect of the heel and posterior portion of the sole.

cc. The **articular branches** are two tiny twigs, given off beneath the internal annular ligament, which supply the ankle joint.

dd. The **internal plantar nerve** (**n. plantaris medialis**) (Fig. 1121), larger than the external, resembles in its distribution the median nerve in the hand. From the point of division of the posterior tibial nerve it courses forward in the foot in company with the internal plantar artery, lying first above the internal annular ligament and the calcanean head of the abductor hallucis and then between the abductor hallucis and the flexor brevis digitorum. Passing thence forward between the flexor brevis hallucis and the flexor brevis digitorum it divides into two terminal branches, an *inner* and an *outer*. In addition to the terminal branches it gives off certain *collateral* twigs.

FIG. 1121.



Dissection of right foot, showing internal aud external plantar nerves and their branches.

The **collateral branches** are muscular, cutaneous and articular in distribution. The *muscular* supply the abductor hallucis and the flexor brevis digitorum. The *cutaneous* pass between the muscles just mentioned to be distributed to the integument of the inner portion of the sole. The *articular* furnish innervation to the inner tarsal and tarso-metatarsal joints.

The **terminal branches** are an inner or mesial and an outer or lateral.

The **inner or mesial terminal branch** (Fig. 1121) courses forward upon the under surface of the abductor hallucis, pierces the plantar fascia posterior to the tarso-metatarsal articulation of the great toe and terminates by extending along the mesial side of that toe as its inner plantar digital nerve. In its course it furnishes filaments to the inner surface of the foot and a twig to the mesial head of the flexor brevis hallucis.

The outer or lateral terminal branch (Fig. 1121) is larger than the inner and is situated below the distal portion of the flexor brevis digitorum and above the deep plantar fascia. After a short forward course it splits into two branches, the lateral of which soon divides into two. There are thus formed three plantar digital nerves (**nn. digitales plantares communes**), each of which at the distal end of its metatarsal space divides into two digital nerves (**nn. digitales plantares proprii**), the inner supplying the contiguous sides of the great and second toes, and the middle and outer being distributed similarly to respectively the second and third and third and fourth toes. The inner of the three sends a filament to the first lumbricalis, the middle sometimes to the second lumbricalis, while the outer forms an inosculation with the external plantar nerve. In addition to innervating the muscles enumerated and the integument of the plantar surface of the mesial three and one-half toes, each of the digital nerves sends tiny filaments toward the dorsum for the supply of the nails and the tips of the toes.

ee. The **external plantar nerve** (**n. plantaris lateralis**) (Fig. 1121) is a smaller nerve than the internal and corresponds in its arrangement and distribution with the palmar branch of the ulnar nerve. After separating from the internal plantar beneath the internal annular ligament, it follows a course in company with the external plantar artery obliquely forward and outward above the flexor brevis digitorum and below the flexor accessorius. Reaching the interval between the abductor minimi digiti and the flexor brevis digitorum it divides near the head of the fifth metatarsal bone into superficial and deep terminal branches.

Branches of the external plantar, like those of the internal, include: *collateral* and *terminal* branches.

The **collateral branches** comprise muscular and cutaneous twigs. The *muscular* branches are given off soon after the origin of the parent nerve and supply the flexor accessorius and the abductor minimi digiti. The *cutaneous* branches are a series of small twigs which follow the septum between the flexor brevis digitorum and the abductor minimi digiti and become superficial by piercing the deep plantar fascia. They supply the integument of the lateral portion of the sole.

The **terminal branches** are: the superficial and the deep.

The **superficial** or **cutaneous branch** (**r. superficialis**) inosculates with a branch of the internal plantar and continues forward in the interval between the flexor brevis digitorum and the abductor minimi digiti, eventually splitting into an external and an internal branch.

The **external branch** (Fig. 1121) sends filaments to the flexor minimi digiti and the interossei muscles of the fourth metatarsal space, after which it becomes cutaneous near the fifth metatarso-phalangeal articulation and continues forward as the plantar digital nerve for the lateral aspect of the fifth toe.

The **internal branch** (Fig. 1121) courses forward in the fourth metatarsal space, at whose distal end it separates into two filaments which supply the opposed surfaces of the fourth and fifth toes. The digital branches send filaments dorsally for the nails and the tips of the toes.

The **deep** or **muscular branch** (**r. profundus**) accompanies the external plantar artery in an obliquely forward and outward course above the adductor obliquus hallucis and the flexor accessorius and below the interossei muscles. It forms an arch (Fig. 1121) whose convexity is directed forward and outward, and terminates in the region of the base of the great toe. From the convex aspect of the arch are given off the filaments which innervate the interossei muscles of the first, second, third and sometimes the fourth interosseous space. Other muscular twigs supply the adductores obliquus and transversus hallucis and the outer three lumbricales, the branch to the second lumbricalis first passing beneath the adductor transversus hallucis. The branches to all of these muscles enter their deep surface. In addition to the muscular distribution, articular twigs are furnished to the tarsal and tarso-metatarsal articulations.

THE PUDENDAL PLEXUS.

The pudendal plexus (**plexus pudendus**) is the downward continuation of the sacral plexus, and, whilst each retains more or less its individuality as a distinct structure, there is no sharp line of demarcation between the two. Considerable interlacing and overlapping is the rule, so that often some of the important branches of the pudendal plexus are derivatives to a large extent from the elements giving rise to the sacral plexus.

The pudendal plexus (Fig. 1122) is situated on the posterior wall of the pelvis and is formed by contributions from the anterior primary divisions of the first, second and third sacral nerves, from the entire anterior primary divisions of the fourth and fifth sacral and from the coccygeal nerve.

Communications.—The nerves helping to form the plexus receive gray rami communicantes from the gangliated cord of the sympathetic, which join them shortly after the nerves emerge from their intervertebral foramina.

Branches.—The branches of the pudendal plexus are: (1) the *visceral*, (2) the *muscular*, (3) the *perforating cutaneous*, (4) the *small sciatic*, (5) the *pudic* and (6) the *sacro-coccygeal*.

FIG. 1122.

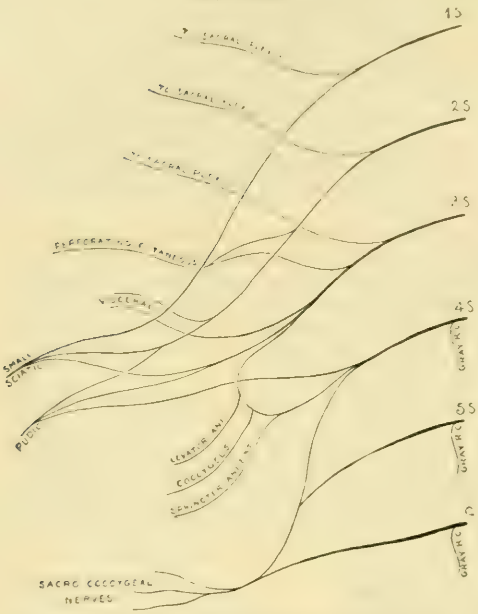
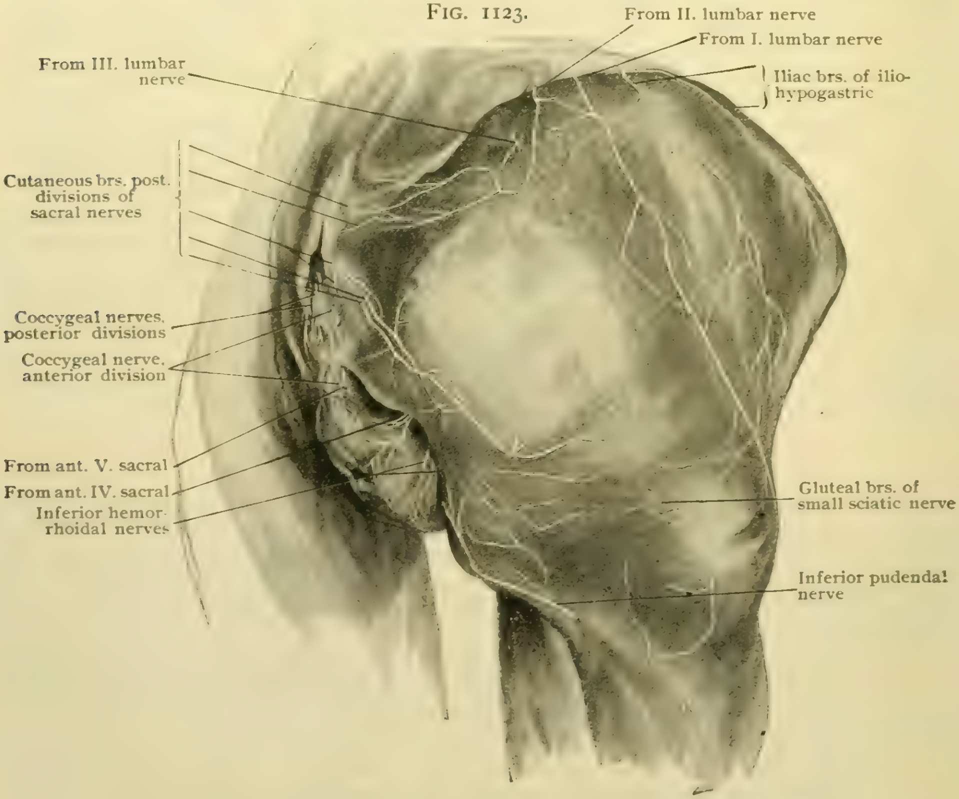


Diagram illustrating plan of pudendal and coccygeal plexuses.

1. The **visceral branches** are really white rami communicantes. They are derived from the second and third or third and fourth sacral nerves and are distributed to the pelvic viscera by way of the pelvic plexus of the sympathetic. The details of these nerves are described with the pelvic plexus of the sympathetic (page 1374).

2. The **muscular branches** furnish innervation to the levator ani, the coccygeus and the external sphincter ani. They arise from a loop-like interlacement of nerve-fibres, formed by the third and fourth sacral nerves, with sometimes the addition of fibres from the second. The nerve to the *external sphincter* pierces the great sacro-sciatic ligament and the coccygeus muscle, sending filaments to the latter, and enters the ischio-rectal fossa, lying between the edge of the gluteus maximus and the sphincter ani externus. It supplies the

FIG. 1123.



Superficial dissection of right buttock and adjacent regions, showing cutaneous nerves.

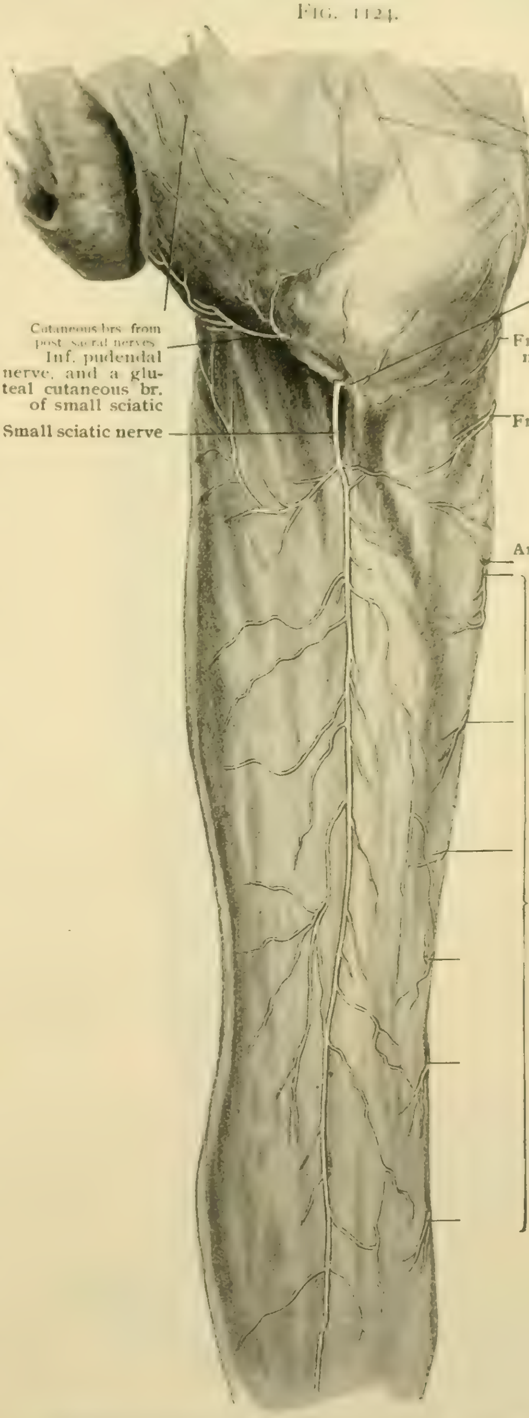
posterior portion of the external sphincter and distributes sensory fibres to the integument over the base of the ischio-rectal fossa and the tip of the coccyx.

Variation. — This nerve, instead of piercing the coccygeus, may pass between that muscle and the levator ani.

The nerve to the *levator ani* is derived usually from the third and fourth, sometimes the second and third, sacral nerves and enters the muscle by piercing its mesial surface.

3. The **perforating cutaneous nerve** (Fig. 1126) is an inconstant branch, being found in about two thirds of the bodies examined. It springs from the dorsal aspect of the second and third sacral nerves and at its point of origin may be associated with the pudic or the small sciatic. Passing downward and backward it pierces the great sacro-sciatic ligament in company with the coccygeal branch of the sciatic artery and winds around the lower border of, or in rare instances pierces, the gluteus maximus. Perforating the deep fascia slightly lateral to the coccyx, it becomes superficial and is distributed to the integument over the inner and lower portion of the gluteus maximus.

Fig. 1124.

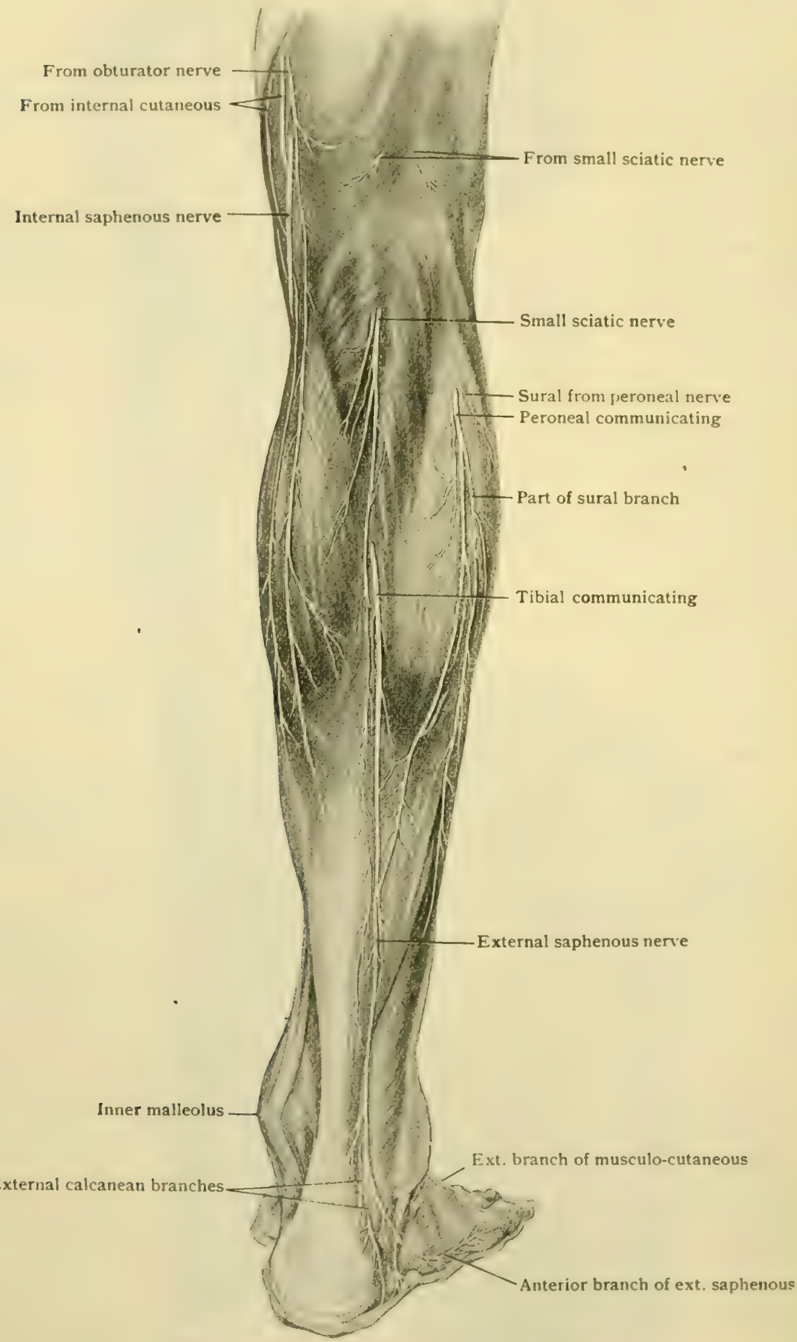


Superficial dissection of right buttock and thigh, showing cutaneous nerves of posterior surface.

Variations. — Instead of piercing the ligament it may accompany the pudic nerve or pass between the ligament and the gluteus maximus. It may be replaced by a branch of the small sciatic or by a nerve, called by Eisler

the *n. perforans coccygeus major*, which arises from the third and fourth or fourth and fifth sacral and pierces the coccygeus muscle.

FIG. 1125.



Cutaneous nerves of posterior surface of right leg.

4. THE SMALL SCIATIC NERVE.

The small sciatic nerve (n. cutaneus femoris posterior) (Fig. 1114) is a purely sensory structure. It originates from the back of the first, second and third, or

from only the second and third, sacral nerves, the upper root usually being associated with one of the roots of the inferior gluteal nerve, and the lower root with the perforating cutaneous or the pudic nerve. Leaving the pelvis through the great sacro-sciatic foramen below the pyriformis, it descends in the gluteal region between the tuber ischii and the great trochanter, posterior to the great sciatic nerve and anterior to the gluteus maximus, accompanied by the inferior gluteal nerve and the sciatic artery. Emerging into the thigh at the lower border of the gluteus maximus it continues downward beneath the deep fascia and superficial to the hamstring muscles to a short distance above the knee, where it pierces the deep, and becomes an occupant of the superficial, fascia. Thence it passes downward through the roof of the popliteal space and through the upper part of the calf, in the latter situation accompanying the external saphenous vein and inosculating with the external saphenous nerve. It rarely extends beyond the middle of the calf, tapering off into tiny threads which are distributed to the skin of the posterior surface of the upper half or two thirds of the leg (Fig. 1125.)

Branches of the small sciatic nerve are: (*a*) the *inferior pudendal*, (*b*) the *gluteal*, (*c*) the *femoral* and (*d*) the *sural*.

a. The **inferior pudendal or perineal branch** (**rr. perineales**) (Fig. 1126) leaves the parent nerve at the lower margin of the gluteus maximus, curves mesially below the tuberosity of the ischium and over the origin of the hamstrings and courses through the groove between the thigh and the perineum. Piercing the deep fascia lateral to the pubic ramus, it enters the perineum and supplies the integument of the scrotum and base of the penis, or of the labium majus and clitoris. Branches are distributed to the skin of the upper mesial portion of the thigh and to the perineal body and anus. This nerve communicates with the ilio-inguinal nerve and with the perineal and inferior hemorrhoidal branches of the pudic nerve. It may pierce the great sacro-sciatic ligament.

b. The **gluteal cutaneous branches** (**rr. clunium inferiores**) (Fig. 1124) consist of two, three or more stout filaments which arise from the small sciatic a short distance above the inferior margin of the gluteus maximus, around which they wind. Piercing the fascia lata individually they turn upward over the lower portion of the gluteus maximus and are distributed to the skin of the inferior gluteal region, as far externally as the great trochanter and internally almost to the coccyx. The outer branches overlap the terminal twigs of the posterior branch of the external cutaneous nerve and the posterior primary divisions of the first, second and third lumbar nerves. The inner branches sometimes pierce the great sacro-sciatic ligament; they reinforce or may replace the perforating cutaneous nerve.

c. The **femoral branches** (Fig. 1124) consist of two series of twigs, an internal and an external, which pierce the fascia lata of the posterior aspect of the thigh and supply the integument of that region.

d. The **sural branches** (Fig. 1125) are usually two terminal twigs which innervate to a varying extent the integument of the back of the leg, sometimes not extending beyond the confines of the popliteal space and sometimes continuing all the way to the ankle. They inosculate with the external saphenous nerve, and when they are lacking their place is taken by the external saphenous.

Variations.—In those cases in which the internal and external popliteal nerves are separate from their incipiency, the small sciatic also is double. The ventral portion accompanies the internal popliteal and gives off the inferior pudendal and internal femoral branches, while the dorsal portion accompanies the external popliteal and gives off the gluteal and external femoral branches. Sometimes the small sciatic is joined in the thigh by a branch from the great sciatic.

5. The Pudic Nerve.

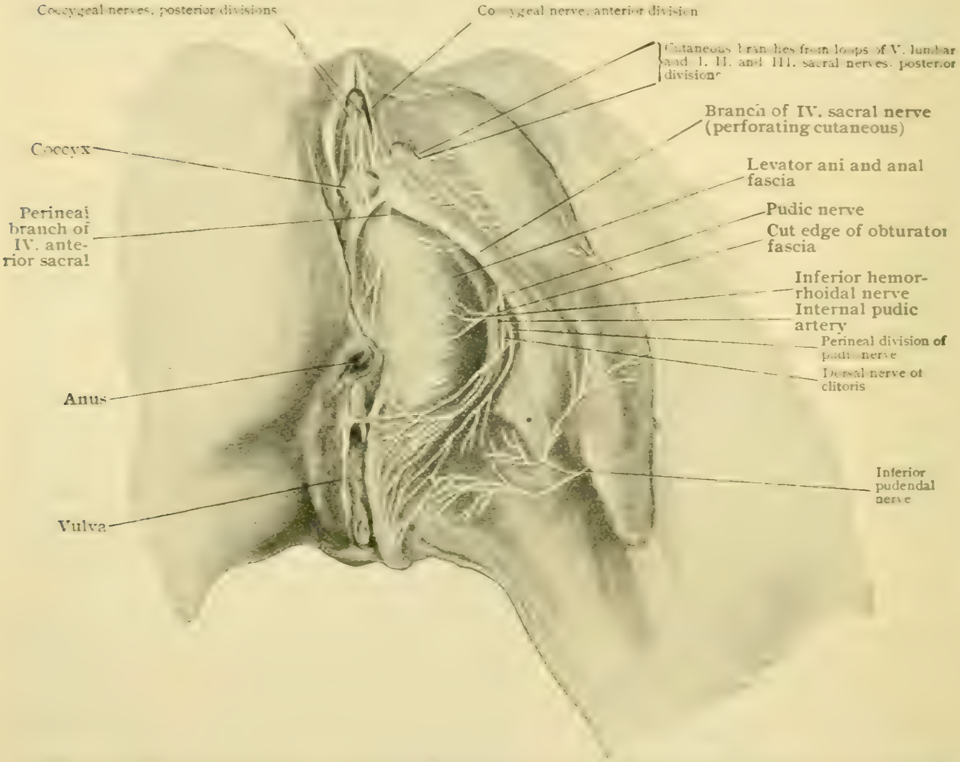
The pudic nerve (**n. pudendus**) arises from the front of the second, third and fourth sacral nerves, its main root coming from the third and there being a doubtful root from the first. Leaving the pelvis by way of the great sacro-sciatic foramen between the pyriformis and the coccygeus and below the great sciatic nerve, it passes forward, with the internal pudic artery and the nerve to the obturator internus, over the base of the lesser sacro-sciatic ligament to the spine of the ischium (Fig. 1126). Reaching the small sacro-sciatic foramen internal to the internal pudic artery, the nerve traverses this opening and enters the ischio-rectal fossa, where it gives off the inferior hemorrhoidal nerve. The main trunk courses forward in a canal (Alcock's) in the obturator fascia on the outer wall of the ischio-rectal fossa

(Fig. 1126), at whose anterior portion the nerve approaches the base of the triangular ligament and divides into its terminal branches, the perineal and the dorsal nerve of the penis or clitoris.

Branches of the pudic nerve are: (*a*) the *inferior hemorrhoidal nerve*, (*b*) the *perineal nerve* and (*c*) the *dorsal nerve of the penis* or *clitoris*.

a. The **inferior hemorrhoidal nerve** (**nn. hemorrhoidales inferiores**) (Fig. 1127) is usually given off by the pudic upon entering the ischio-rectal fossa, but it may be derived directly from the plexus, its fibres being offshoots of the third and fourth sacral nerves. In company with the inferior hemorrhoidal vessels it passes mesially across the base of the ischio-rectal fossa toward

FIG. 1126.



Superficial dissection of right side of female perineum and adjacent region, showing cutaneous nerves; obturator fascia has been partly removed to expose pudic nerve and accompanying blood-vessels in canal on outer wall of ischio-rectal fossa.

the anus, on approximating which it splits into a number of filaments, which supply the external sphincter and the integument of the anal region, and inosculate with the small sciatic, pudic and fourth sacral nerves.

b. The **perineal nerve** (**n. perinei**) (Fig. 1126) is one of the terminal branches of the pudic and arises at the bifurcation of that nerve near the posterior margin of the triangular ligament. Soon after its origin it splits into: (*aa*) a superficial and (*bb*) a deep branch.

aa. The **superficial branch** is entirely sensory and consists of two parts, a lateral or posterior and a mesial or anterior. These pass forward toward the base of the scrotum in company with the superficial perineal vessels.

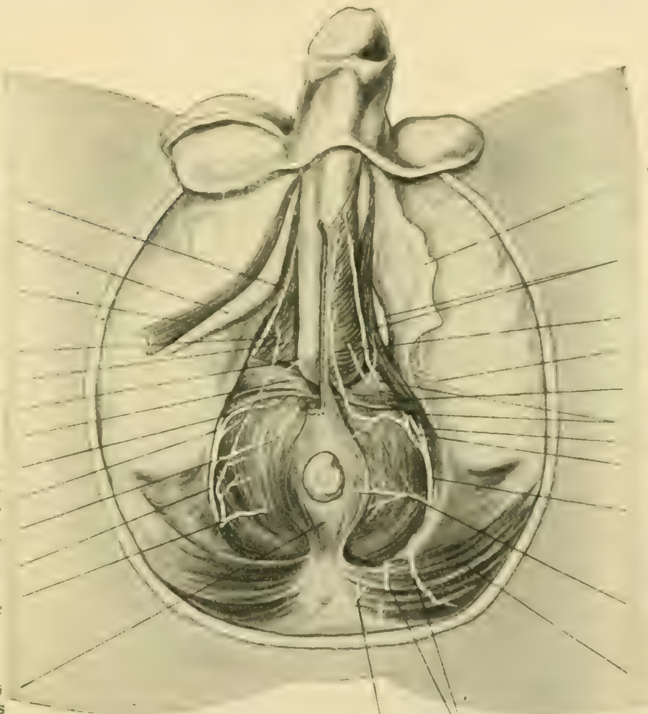
The *lateral*, *external* or *posterior branch* courses along the lateral margin of the perineum, distributing twigs in this region and sometimes sending branches to the inner aspect of the thigh and a filament to the origin of the ischio-cavernosus muscle (Schwalbe).

The *mesial*, *internal* or *anterior branch* is larger than the lateral and is more deeply placed. It pierces the posterior margin of the triangular ligament and runs forward either beneath or through the transversus perinei muscle. It splits into two or more branches (**nn. scrotales vel labiales posteriores**) which inosculate freely with each other and supply the integument of the scrotum or labium majus. They communicate with the pudendal branch of the small sciatic nerve and with the inferior hemorrhoidal.

bb. The **deep branch** of the perineal nerve is mainly muscular and consists of a single trunk which breaks up into several branches, whose main destination is the muscles of the perineum. Passing forward from the ischio-rectal fossa it enters the deep perineal interspace and sends filaments to the external sphincter ani, the levator ani, the transversus perinei, the ischio-cavernosus, the bulbo-cavernosus or sphincter vaginæ and the compressor urethræ. One branch, the **nerve to the bulb**, accompanied by the artery of the same name, enters the bulb, supplying its tissue and that of the corpus spongiosum, and innervating the urethra as far forward as the glans penis.

c. The **dorsal nerve of the penis** (**n. dorsalis penis**) (Fig. 1127) a terminal branch and the most deeply situated of all the branches of the pudic, accompanies the dorsal artery of the penis through the deep perineal interspace. It lies beneath the crus penis, the ischio-cavernosus muscle and the inferior layer of the triangular ligament and over the compressor urethræ

FIG. 1127.



Dissection of male perineum, showing distribution of pudic nerve; on left side of body Colles' fascia has been reflected to expose superficial perineal interspace; dorsal nerve of penis is seen in deep interspace on right side.

muscle. Piercing the inferior layer of the triangular ligament and the suspensory ligament of the penis it reaches the dorsum of the penis, along which it courses as far as the glans. It gives off the *nerve to the corpus cavernosum*, which pierces the triangular ligament and supplies the erectile tissue of the crus penis and corpus cavernosum. The main nerve innervates the anterior two thirds of the penis, including the glans, and sends off ventral branches which pass around to the under surface of the organ.

The **dorsal nerve of the clitoris** (**n. dorsalis clitoridis**) (Fig. 1128), while much smaller than the dorsal nerve of the penis, has a corresponding course and distribution.

The dorsal nerve of the penis or clitoris communicates with the inferior pudendal branch of the small sciatic.

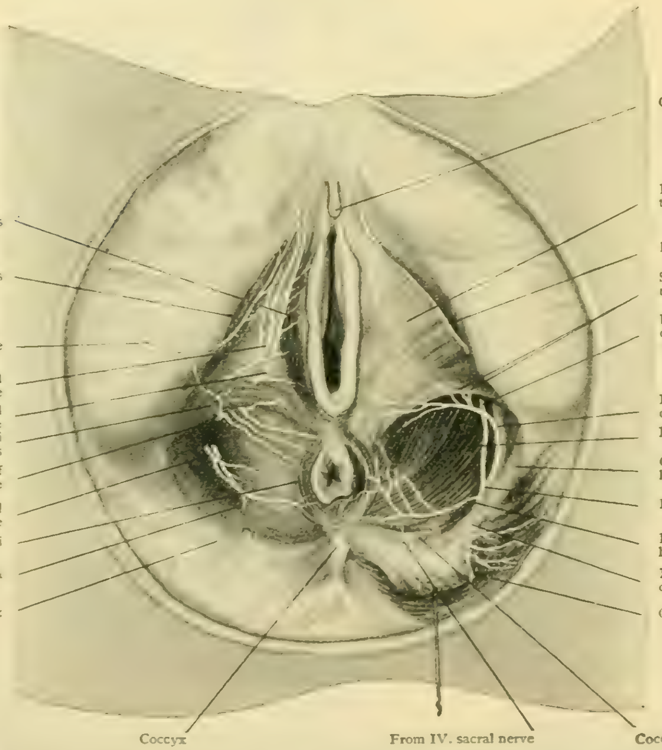
Variations.—The pudic may receive a root from the fifth lumbar, in the high form of plexus. A root from the fifth sacral is described by Henle. The inferior hemorrhoidal may pierce either the great or the small sacro-sciatic ligament, and the former of these ligaments may be perforated by the lateral superficial perineal nerve.

THE COCCYGEAL PLEXUS.

6. The **sacro-coccygeal nerves** (nn. anococcygei) are derived from a small nerve inosculation called the coccygeal plexus (**plexus coccygeus**), a structure formed by the fifth sacral and the coccygeal nerve, with a contribution from the fourth sacral which descends over or through the great sacro-sciatic ligament. The fifth sacral, having been joined by this twig from the fourth, descends along the margin of the coccyx and is joined by the coccygeal nerve, the resulting nerve-bundle constituting the coccygeal plexus. From it arise minute filaments which pierce the great sacro-sciatic ligament and are distributed to the integument in the immediate neighborhood of the coccyx (Fig. 1084).

Practical Considerations.—Of the branches of the sacral plexus, the *great sciatic nerve* is the most important, owing to its size, its extensive distribution and its exposed position. The greater part of the sacral plexus is continued into the

FIG. 1128.



Dissection of female perineum, showing nerves; anal fascia in position on right side of body, removed on left; Colles' fascia removed on right side, exposing superficial perineal interspace; superior layer of triangular ligament, denuded of muscular tissue, seen on left side.

nerve. Except in complete lesions of the spinal cord this nerve is rarely paralyzed in all its branches. The paralysis may result from fractures of the lumbar vertebræ, of the sacrum or of the innominate bone, from pressure of tumors in the pelvis or of the child's head in labor or from the use of forceps. It is the structure in greatest danger in dislocation of the hip, since the head of the femur in the most frequent varieties sweeps backward against this nerve. In the reduction of these posterior dislocations the nerve has been hooked up by the head and made to pass across the front of the neck of the bone. From its close relation to the head and neck, it may be injured in violent movements of the hip joint without dislocation.

It passes out of the pelvis through the greater sacro-sciatic foramen, below the pyriformis muscle, and after curving outward and downward under the gluteus maximus muscle it continues its course, approximately, in a line from a point midway

between the greater trochanter and the tuberosity of the ischium above to the middle of the popliteal space below. At about the junction of the middle and lower thirds of the thigh it divides into the internal and external popliteal nerves. Below the gluteus maximus muscle it is comparatively superficial, so that tenderness of the nerve, as from sciatica, is easily elicited by pressure. At the point where it emerges from under the gluteus maximus it is readily reached for operation. After a vertical incision through the skin and fascia at this level, the biceps muscle is exposed. The lower margin of the gluteus maximus is raised and the biceps drawn inward, when the nerve can be easily hooked up with the finger. Because of the great importance of this nerve to the lower extremity it is not advisable to excise or divide it as this would paralyze its whole area below. Stretching is the only justifiable operation, although the results obtained are often disappointing, and the operation may cause acute neuritis. According to Trombetta, it will require a tension equal to the weight of 183 lbs. to break it, and it is more likely to yield at its attachment to the spinal cord than elsewhere. It should, therefore, tolerate a stretching force of from 100 to 160 lbs. (Treves). A safe working rule is to use a force sufficient to raise the affected limb from the table, the patient lying in the prone position.

It has been observed that when the paralysis is due to some pressure upon the nerves of the sacral plexus within the pelvis it is often confined to the *peroneal* or *external popliteal nerve*, or is most marked in it. This has been explained by the fact that the fibres for the peroneal nerve lie close together directly on the pelvic bones, and are, therefore, particularly exposed to pressure. They arise for the most part from the lumbo-sacral cord, formed by the fourth and fifth lumbar and first sacral nerves, which lie directly on the innominate crest, the rest of the plexus lying on the pyriformis muscle.

In paralysis of the *external popliteal* or *peroneal nerve* the extensors of the foot and toes, the tibialis anticus and the peronei muscles are involved. The foot hangs down from its own weight (foot drop), and turns in from paralysis of the peronei. In some cases the anterior tibial muscle escapes. In walking the knee must be unduly flexed to prevent the toes from dragging on the ground and the arch of the foot is flattened from the loss of the support given to the arch by the peroneus longus. If sensation is disturbed it will be only to a slight extent over the anterior part of the leg about the shin, and outward from this on the dorsum of the foot and toes, but not at the sides of the foot. The peroneal nerve may be divided accidentally in a subcutaneous tenotomy of the biceps tendon for contraction at the knee, the nerve lying close to the inner border of the tendon. It may be injured by external violence, as it passes around the head and neck of the fibula, where if necessary, an incision will easily expose it ; or it may be injured by pressure, as in prolonged kneeling.

In paralysis of the *internal popliteal nerve* all the other muscles of the leg, including the superficial and deep flexors, the tibialis posticus, the plantar muscles and interossei are affected. The patient cannot extend the ankle and therefore cannot stand on his toes. The toes cannot be flexed or moved sideways. Sensation is disturbed on the inner and posterior surface of the leg, the outer border of the foot, the sole and the plantar surface of the toes.

In paralysis of the *entire sciatic nerve* the flexors of the knee also are involved, so that the patient cannot bring the heel toward the buttock. If only one sciatic is involved he can still walk by fixing the knee in extension, the whole limb being brought forward by the quadriceps extensor, which is supplied by the anterior crural nerve.

THE SYMPATHETIC SYSTEM OF NERVES.

The sympathetic portion (**systema nervorum sympatheticum**) of the peripheral nervous system differs from that already described—the spinal and the cranial nerves—in being particularly concerned in carrying efferent and afferent impulses to and from the thoracic and abdominal organs (collectively termed the *splanchnic area*), in contrast to the great somatic (skeletal) masses of voluntary muscle. Whilst the paths for the afferent or sensory impulses conducted from the splanchnic area differ in no important respect from those formed by the cerebro-spinal nerves, the efferent or motor paths are peculiar (*a*) in supplying the involuntary and cardiac muscle and

the glandular tissue and (*b*) in consisting of at least two, sometimes of more, links between the source of the impulse (the spinal cord) and the structure upon which it is expended. It is these interposed links that constitute the sympathetic elements proper—the *sympathetic neurones.* The cell-bodies of these neurones exhibit a marked disposition to become aggregated into larger or smaller collections, which constitute the innumerable *ganglia* that form a conspicuous feature of the sympathetic system, whilst their axones serve to connect the ganglia with the terminal structures (muscles or glands) or with other neurones. It is evident, therefore, that the sympathetic system consists of a complex of spinal and sympathetic fibres intermingled with groups of ganglion-cells. The latter are, for the most part, stellate in form and provided with axones which, while often pursuing a long course as *splanchnic efferents*, acquire only partially or not at all a medullary coat and hence may be classified usually as nonmedullated fibres. Since the spinal fibres are provided with this covering, the bundles of such fibres present the whitish color distinguishing medullated strands, in contrast to the grayish tint of the strands of the nonmedullated sympathetic filaments. It is upon this histological variation of their predominating fibres that the difference recognized in the white and gray rami communicantes, presently to be described, depends. Although the supply of the thoracic, abdominal and pelvic organs constitutes an important part of the duty of the sympathetic nerves, it is by no means their entire concern, the innervation of the involuntary muscle of the vessels and of the skin and the glands throughout the body being likewise their task. In order to meet their obligations to the structures within the body cavities, the sympathetic nerves naturally follow the course of the blood-vessels, with the result that every artery of consequence within these regions is surrounded by a more or less elaborate net-work, these plexuses in most cases bearing the names of the arteries which they accompany. In order to provide for the outlying tracts of involuntary muscle contained within the blood-vessels outside the body-cavities and within the skin, as well as for the glands, the sympathetic fibres join, by way of the gray rami communicantes, the somatic spinal nerves, which they accompany to all parts of the body. For this reason the peripheral somatic nerve-trunks contain three varieties of fibres—afferent and efferent spinal and efferent sympathetic.

FIG. 1129.

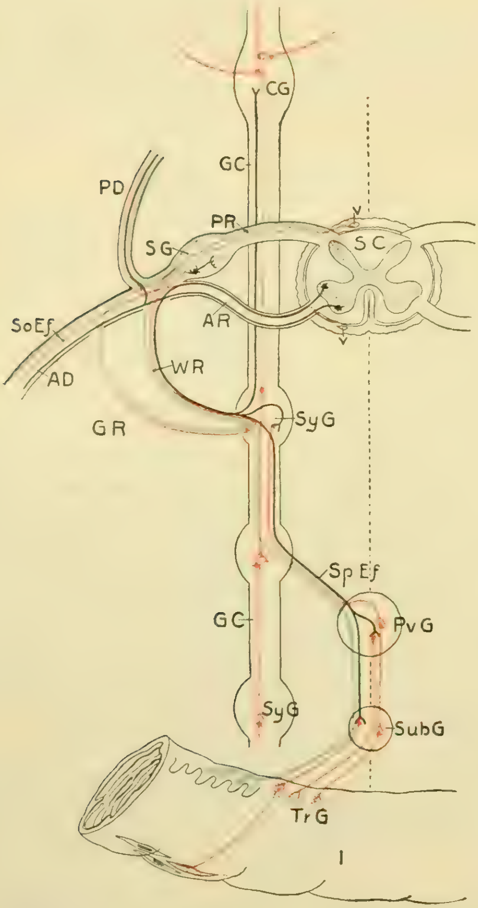
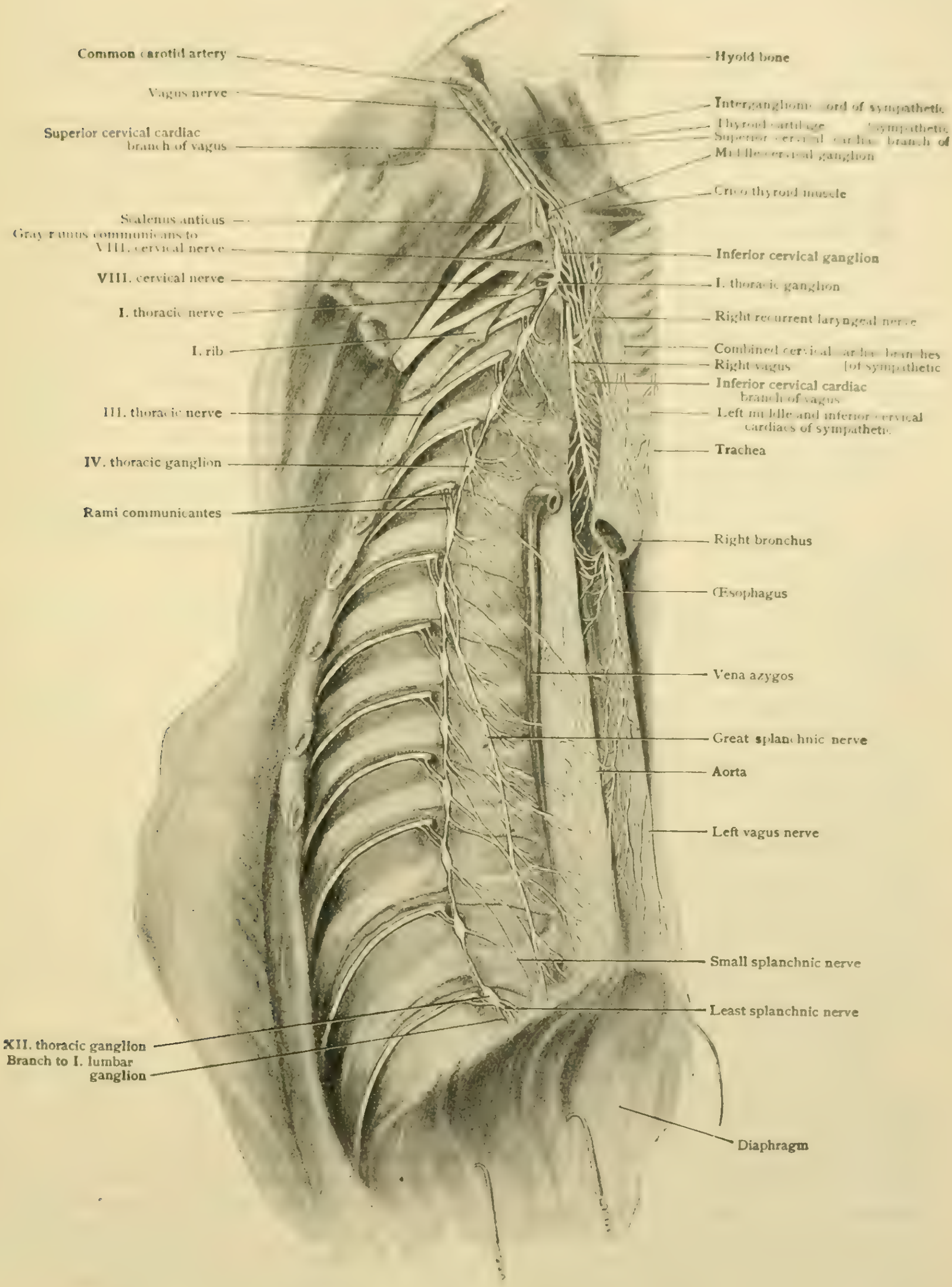


Diagram showing constitution of sympathetic system; spinal efferents are black; sympathetic efferents are red; sympathetic (visceral) afferents are blue; *SC*, spinal cord; *AR*, *PR*, anterior and posterior root of spinal nerve; *SG*, spinal ganglion; *AD*, *PD*, anterior and posterior primary divisions; *WR*, *GR*, white and gray rami communicantes. *GC*, gangliated cord; *SyG*, sympathetic ganglia; *CG*, cervical sympathetic ganglion; *PvG*, *SubG*, *TrG*, prevertebral, subsidiary and terminal ganglia; *SpEf*, splanchnic efferents; *SoEf*, somatic efferents; *V*, vessels of the spinal meninges; *I*, intestine.

Constitution and General Arrangement.—The sympathetic system serves to receive, rearrange and distribute the visceral filaments of the cerebro-spinal nerves,

FIG. 1130.



Dissection showing right gangliated cord of sympathetic and its branches.

and to complete, by the interposition of one or more of its especial neurones, the path for the impulses brought by such fibres to the objective organs. It comprises

two principal parts, the *gangliated cords* and the *plexuses*, with their associated *ganglia*.

The **gangliated cord** (**truncus sympatheticus**), one of a symmetrically placed pair of gangliated trunks situated anterior or lateral to the bodies of the vertebræ (Fig. 1133), begins in the head and extends through the neck, thorax and abdomen to the lower portion of the pelvis. In the head it consists of a plexus of fibres continued up from the neck in an intricate interlacement which follows the internal carotid artery ; and in the pelvis it terminates by the two cords forming a loop or fine inosculation, situated anterior to the coccyx and containing the *coccygeal ganglion* or *ganglion impar*.

The **plexuses** (**plexus sympathetici**) are a series of more or less distinct collections of groups of nerve-cells (ganglia) and fibres, situated mainly in the axial line and giving off and receiving fibres connected with the various viscera of the trunk. The component elements of the plexuses and, indeed, of the entire sympathetic system, are the *ganglia* and the *nerve-fibres*.

The **ganglia**, whilst following a general plan of arrangement as to number, size and position, are subject to wide individual variations and, moreover, where they approach a segmental type, as in the gangliated cord, there is considerable deviation from the arrangement presented by the cerebro-spinal system. A ganglion may or may not be connected with a spinal nerve, but it is always linked by **association cords** with other ganglia. According to their position, three varieties of ganglia are recognized. One group includes the **prevertebral ganglia** (**g. trunci sympathetici**), those found as nodes in the gangliated cord ; a second variety comprises the **collateral** or **intermediate ganglia** (**g. plexuum sympatheticorum**), which lie either on the peripheral branches of the gangliated cord or in a prevertebral plexus ; whilst to the third set belong the innumerable minute **terminal ganglia**, composed of nerve-cells which lie at or near the visceral distributions of the sympathetic fibres.

Each ganglion consists of an indefinite number of multipolar neurones, which possess one axone and a number of dendrites, the whole cluster of cells being enclosed in an envelope of fibrous tissue. The axone is often medullated in the immediate vicinity of its cell, but usually loses this sheath as it gets farther and farther away from its origin. The course taken by the axone of a prevertebral ganglion-cell may be one of three : (1) it may pass by means of an association cord into an adjoining prevertebral ganglion, (2) it may proceed as a constituent of a gray ramus communicans to join a spinal nerve or (3) it may follow a splanchnic efferent toward a viscus.

The **nerve-fibres** encountered within the sympathetic system include two sets : (*a*) those derived from the cerebro-spinal system, which are usually medullated, and (*b*) the sympathetic fibres proper, for the most part nonmedullated, although as stated above, many of the axones possess a medullary sheath for a short distance beyond their origin from the nerve-cell. This distinction between medullated and nonmedullated fibres is, however, somewhat indefinite, since the medullated spinal fibres often become nonmedullated before terminating, whilst the sympathetic fibres occasionally are medullated throughout their course.

Rami Communicantes.—Where the typical segmental arrangement prevails, as in the thoracic region, each spinal nerve is connected with the adjacent gangliated cord by a pair of short nerve-trunks, known as the *rami communicantes* (Fig. 1129). These are divided into two groups, the *white rami* and the *gray rami*, a distinction depending primarily upon the difference in the appearance of the strands when seen in the fresh condition ; this distinction, moreover, corresponds with the histological difference above noted—white rami appearing so in consequence of the preponderance of opaque medullated fibres, and the gray rami possessing the darker tint on account of the absence of the refracting myelin coat. The rami communicantes pass directly between the spinal nerves and the gangliated cord, in relation to the latter joining either a ganglion or an association cord between nodes.

The **white rami communicantes** are composed almost exclusively of the visceral branches of certain of the spinal nerves which use the sympathetic system as the pathway by which they arrive at their destination. They consist of fasciculi of

medullated nerve-fibres derived from both the anterior and the posterior roots of the spinal nerves. The fibres arising from the anterior root are called the *splanchnic efferent fibres* and those from the posterior root the *splanchnic afferent.* Not all of the spinal nerves, however, give off white rami, these strands of communication forming a *thoraco-lumbar group*, from the first or second thoracic to the second or third lumbar nerve inclusive, and a *sacral group*, derived from the second and third, or third and fourth sacral nerves. The cervical nerves do not give off white rami.

The **splanchnic efferent fibres** are the axones of cells located within the lateral horn of the gray matter of the spinal cord. They furnish motor impulses to the unstriped muscle of the vessels and viscera, and secretory ones to the glands of the splanchnic area; they also convey motor impulses to the heart. Leaving the spinal cord by way of the anterior root, they pass peripherally, enter a white ramus communicans and reach the gangliated cord. One of three courses is then pursued by these fibres: (1) they may end at once by forming arborizations around cells in the ganglion which they first enter, (2) they may pass through this ganglion, thence up or down through an association cord to end around the cells of a node of the gangliated cord above or below the level of entrance, or (3) they may course through the gangliated cord and one of its visceral branches, and terminate in arborizations around the cells of a prevertebral or of a collateral ganglion. It is possible that in some cases the spinal efferents may continue without interruption through the several divisions of its path as far as the terminal ganglia. The path connecting the spinal cord with the involuntary muscle always consists of two fibres, the *preganglionic* and *postganglionic*. The latter is the axone of the sympathetic neurone and always forms the last link of the path carrying the stimulus to the involuntary muscle.

The **splanchnic afferent fibres** are the sensory fibres of the splanchnic area and consist of the dendrites of cells situated within the intervertebral ganglia on the posterior roots of the spinal nerves. Whilst the greater number of these fibres are found in the white rami, a few are thought to be constituents of the gray rami. Beginning in the viscera, they run centrally, without interruption, through the terminal and collateral ganglia, through the gangliated cord and the white (or gray) rami to the spinal nerve, and thence after coming into relation with the cells of the ganglion of the posterior root, they pass by way of the posterior roots into the spinal cord.

The **gray rami communicantes** are bundles of axones of sympathetic neurones which pass from the gangliated cord to each one of the entire series of spinal nerves. The reason of this generous provision will be evident when the purpose of the communications effected by the gray rami is recalled, namely, to provide sympathetic filaments to the outlying muscles and glands by way of the convenient path afforded by the distribution of the somatic nerves. Mingled with the gray fibres, a few of the medullated variety are often encountered; these are probably partly splanchnic afferent fibres and partly medullated sympathetic fibres. Variation in the origin of the gray rami from the gangliated cord is not uncommon; they may arise either from a ganglion or from the association cord between two ganglia; after leaving the gangliated cord, a single ramus may divide and supply two spinal nerves; or the reverse may happen, two or more rami arising independently and either separately or after fusing, joining a single spinal nerve.

The further course of the sympathetic fibres, after having joined the spinal nerves by way of the gray rami, is as follows: (1) they may course peripherally along with the anterior or posterior primary divisions of the spinal nerve and convey vasomotor, pilomotor or secretory impulses to the involuntary muscle and glands of the somatic area; or (2) they may enter the spinal canal by way of the anterior or posterior nerve-roots and be distributed to the spinal meninges, but not to the nervous column. According to Dogiel, it is probable that a small number of axones of sympathetic neurones enter the root-ganglia of the spinal nerves to end in arborizations around cells of the ganglia.

The **association cords** (Fig. 1130) are the longitudinally disposed bundles of fibres comprising the interganglionic portion of the gangliated cord; they contain both white and gray fibres. The gray ones are the axones of sympathetic neurones which are either passing between adjacent or more remote ganglia, or taking an upward or

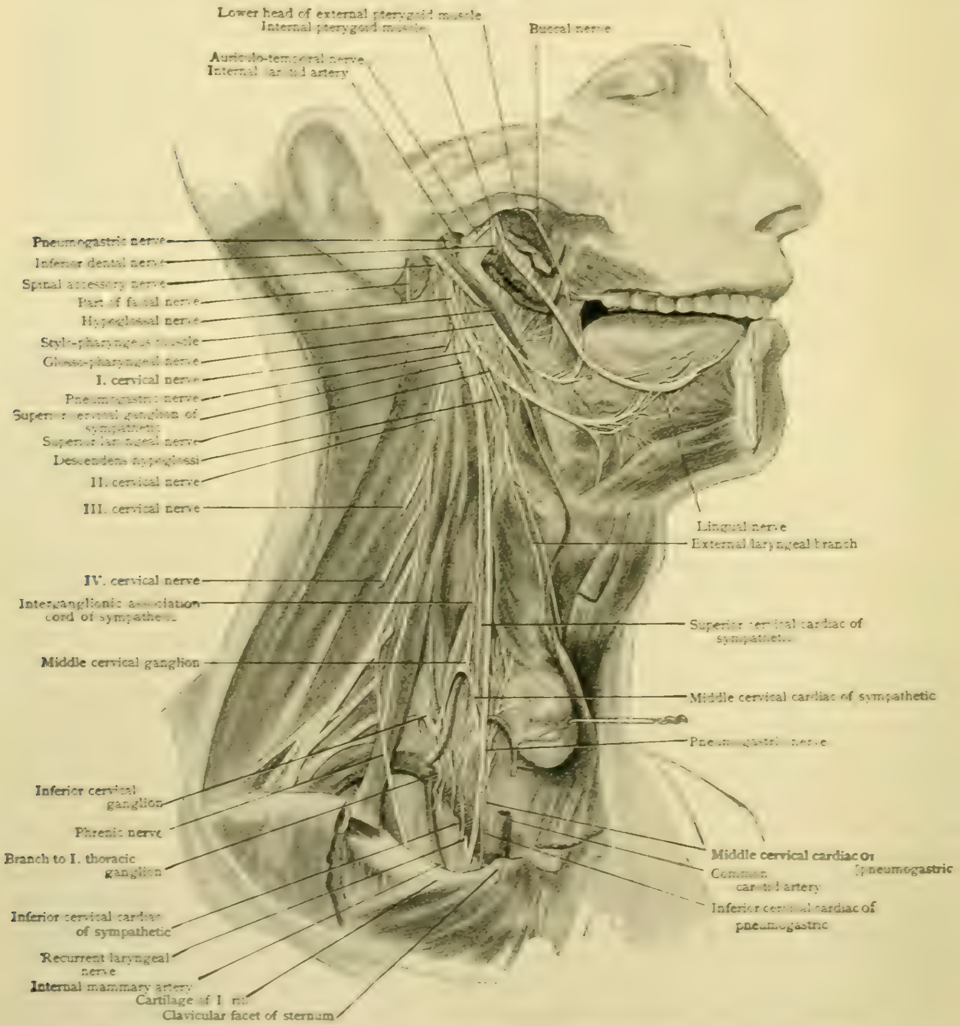
downward course before passing distally to their ultimate splanchnic distribution. The white fibres are either spinal splanchnic efferent or afferent fibres.

The **branches of distribution** from the gangliated cord include the *somatic* and the *visceral.* The **somatic branches** are the gray rami communicantes; the **visceral branches** comprise the splanchnic efferents, which consist of both white and gray efferent fibres, as well as the white splanchnic afferents.

THE CERVICO-CEPHALIC PORTION OF THE GANGLIATED CORD.

The cervico-cephalic portion of the gangliated cord (pars cephalica et cervicalis systematis sympathetici) consists of a series of ganglia, usually three, but often only two, connected by composite association cords (Fig. 1131). It lies posterior to the

FIG. 1131.



Deep dissection of neck, showing cervical portion of sympathetic gangliated cord and its connections

carotid sheath and anterior to the prevertebral fascia and the rectus capitis anticus major and scalenus anticus muscles. Inferiorly it is continued into the thoracic portion of the gangliated cord, and superiorly, at the base of the skull, it forms an intricate plexus around the internal carotid artery, in whose company it enters the

cranium. The small ganglia connected with the trigeminal nerve—the ciliary, the spheno-palatine, the otic and the submaxillary—are regarded as outlying nodes belonging to the cephalic continuation of the gangliated cord.

The dominant characteristic of this portion is the *absence of white rami*, the spinal fibres present reaching the cervical region from the upper thoracic nerves by way of the association cord between the highest thoracic and lowest cervical ganglion, around whose cells, as well as those of the higher cervical ganglia, the processes of the spinal neurones end.

The **distribution** of the cervical portion of the cord includes pupillo-dilator fibres, cardio-accelerator fibres, vasomotor fibres to the arteries of the head, neck and upper extremities, pilomotor fibres to the integument of the head and neck, motor fibres to the involuntary muscles of the orbit and eyelids and secretory fibres to the glands. The branches consist, as elsewhere, of two groups, somatic and visceral, the former reaching their area of distribution by way of certain cranial and spinal nerves, and the latter, either alone or in conjunction with other nerves, forming plexuses which accompany blood-vessels and supply various viscera and vessels of the head, neck and thorax.

The **ganglia** of the cervical portion include a *superior*, a *middle* and an *inferior*.

The Superior Cervical Ganglion.—The superior cervical ganglion (g. cervicale superius) (Fig. 1077) is the largest of the entire sympathetic series, measuring 2–3 cm. in length and 4–6 mm. in width. It rests posteriorly on the rectus capitis anticus major muscle opposite the second and third cervical vertebræ, with the internal carotid artery anterior to it and the vagus nerve to its lateral aspect. With the typical reddish-gray hue of the sympathetic ganglia, it is fusiform in outline, although it may present constrictions, usually three, which indicate its composition of four fused ganglia.

The **somatic branches** consist of (1) *rami communicantes* and (2) some of the *communicating branches* to the cranial nerves.

1. The **rami communicantes** consist of four gray rami which join the anterior primary divisions of the first four cervical nerves.

2. The **communicating branches** to the cranial nerves are given off from the upper portion of the ganglion, (1) one joining the petrous ganglion of the glosso-pharyngeal, (2) others entering the ganglia of the root and trunk of the vagus and (3) another joining the hypoglossal nerve. In addition to these there is frequently given off from the lower portion of the ganglion (4) a branch which joins the external laryngeal nerve.

The **visceral branches** comprise: (1) the *pharyngeal*, (2) the *superior cervical cardiac*, (3) the *vascular* and (4) the *vertebral*.

1. The **pharyngeal branch** or branches (rr. laryngopharyngei) arises from the antero-mesial aspect of the ganglion and courses obliquely inward and downward posterior to the carotid sheath to reach the surface of the middle constrictor of the pharynx. Here it unites with the pharyngeal branches of the glosso-pharyngeal and vagus nerves to form the **pharyngeal plexus** (page 1269), from which fibres are distributed to the muscles and mucous membrane of the pharynx, a few filaments joining the superior and external laryngeal nerves.

2. The **superior cervical cardiac nerve** (n. cardiacus superior) (Fig. 1131) arises as two or three twigs from the ganglion, with sometimes an additional filament from the association cord between the superior and middle ganglia. It courses downward anterior to the longus colli muscle in the posterior part of the carotid sheath, crosses the anterior or the posterior surface of the inferior thyroid artery, and then descends in front of the inferior laryngeal nerve. At the base of the neck the course of the nerve begins to differ on the two sides.

The **right nerve** enters the thorax either anterior or posterior to the subclavian artery and accompanies the innominate artery to the aorta, where it enters the deep cardiac plexus, a few fibres passing to the anterior surface of the aorta. On the way down a few twigs join the inferior thyroid artery and with it enter and supply the substance of the thyroid body.

The **left nerve** upon entering the thorax joins the common carotid artery, along whose lateral and anterior surfaces it courses to the aorta, upon reaching which it

joins the superficial cardiac plexus. In some instances the nerve remains behind the carotid artery and joins the deep cardiac plexus.

A **pretracheal branch**, derived from the loop between the superior cervical cardiac nerve and the inferior laryngeal, descends anterior to the trachea and is distributed to the pericardium and the anterior pulmonary plexus (Drobnik.)

The superior cervical cardiac nerve **communicates** freely in the neck with the middle cardiac and other branches of the sympathetic, and with the external laryngeal and superior cervical cardiac branches of the vagus. In the thorax it inosculates with the inferior laryngeal nerve.

Variations.—The superior, as well as the other cardiac nerves, presents a considerable degree of variation, sometimes to so great an extent as to show no resemblance to the accepted typical plan of arrangement. It is sometimes absent, especially on the right side, and in such event appears to be replaced by a branch from the vagus or from the external laryngeal nerve. It may have no independent course, but join one of the other sympathetic cardiac nerves and reach its destination as a part of the latter.

3. The **vascular branches** comprise plexiform nerve-structures which accompany the terminal divisions of the common carotid artery. They consist of: (*a*) the *external carotid branch* and (*b*) the *internal carotid branch*.

a. The **external carotid branch** (**n. caroticus externus**) (Fig. 1061) joins the external carotid artery and furnishes subsidiary plexuses which accompany the branches of that vessel. In addition to supplying vasomotor fibres to the external carotid tree, sympathetic filaments are furnished to two of the ganglia of the trigeminal nerve. A branch (**radix g. submaxillaris**) from the plexus on the facial artery (**plexus maxillaris externus**) joins the submaxillary ganglion as its sympathetic root, and one or more, the **smallest deep petrosal nerve**, from the plexus on the middle meningeal artery (**plexus meningeus**), forms the sympathetic root of the otic ganglion.

Ganglia of microscopic size have been described on these vascular plexuses. The most important of these, the *temporal ganglion*, is situated on the external carotid at the point of origin of the posterior auricular artery and is said to receive a filament of communication from the stylo-hyoid branch of the facial nerve.

b. The **internal carotid branch** (**n. caroticus internus**) is apparently an upward, cranial extension of the superior ganglion (Fig. 1061). Ascending beneath the internal carotid artery, it accompanies that vessel into the carotid canal, where it divides into two plexuses, the *carotid* and the *cavernous*, the former ramifying on the lateral and the latter on the mesial aspect of the artery. While the individuality of these two is distinct, there are numerous fine fibres connecting them as they pass upward into the cranium.

The **carotid plexus** (**plexus caroticus internus**) is located on the lateral or outer surface of the internal carotid artery at its second bend. In addition to supplying fine plexuses which accompany the branches of the artery to their ultimate ramifications, the following arise from the carotid plexus: (*aa*) the *carotid branches*, (*bb*) the *communicating branch to the abducent nerve*, (*cc*) the *communicating branches to the Gasserian ganglion*, (*dd*) the *great deep petrosal nerve* and (*ee*) the *small deep petrosal nerve*.

aa. The **carotid branches** consist of numerous fine twigs which are supplied to the internal carotid artery.

bb. The **communicating branch to the abducent nerve** consists of one or two twigs which join the nerve as it lies in the wall of the cavernous sinus in close proximity to the internal carotid artery.

cc. The **communicating branches to the Gasserian ganglion** comprise several small filaments which pass to the ganglion; they usually arise from the carotid but sometimes are derived from the cavernous plexus.

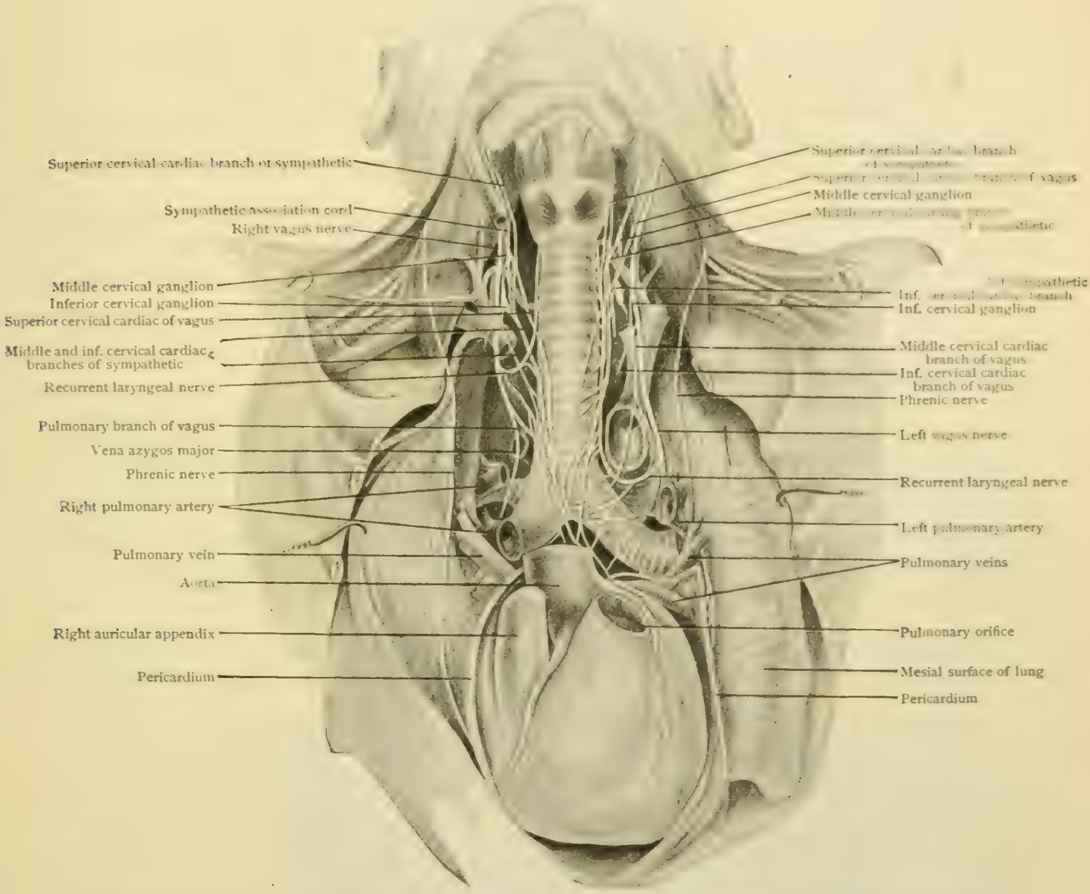
dd. The **great deep petrosal nerve** courses forward to the posterior end of the Vidian canal, where it joins the great superficial petrosal to form the *Vidian nerve* (page 1059), finally entering Meckel's ganglion as its sympathetic root.

ee. The **small deep petrosal nerve** or *n. carotico-tympanicus* joins the tympanic plexus (page 1075), a structure formed by the tympanic branch of the glosso-pharyngeal, a filament from the geniculate ganglion of the facial nerve and the small deep petrosal nerve. In addition

to furnishing twigs to the mucous membrane of the middle ear and vicinity, this plexus contributes a large part of the *small superficial petrosal nerve*, which joins the otic ganglion as its sensory root (page 1246).

The **cavernous plexus** (plexus cavernosus) lies inferior and internal to the internal carotid artery and in intimate relation with the cavernous sinus. Its branches are: (*aa*) the *carotid branches*, (*bb*) the *communicating branch to the oculomotor nerve*, (*cc*) the *communicating branch to the trochlear nerve*, (*dd*) the *communicating branch to the ophthalmic division of the trigeminus nerve*, (*ee*) a *branch to the ciliary ganglion* and (*ff*) *branches to the pituitary body.*

FIG. 1132.



Dissection showing cardiac branches of pneumogastric nerves and of sympathetic cords; aortic arch and branches and pulmonary artery partially removed ; pericardium laid open.

aa. The **carotid branches** are distributed to the internal carotid artery.

bb. The **communicating branch to the oculomotor nerve** joins the latter about at the point where it breaks up into its superior and inferior divisions.

cc. The **communicating branch to the trochlear nerve**, sometimes derived from the carotid plexus, joins the trochlear in the wall of the cavernous sinus.

dd. The **communicating branch to the ophthalmic division of the trigeminus nerve** joins the mesial surface of that nerve.

ee. The **branch to the ciliary ganglion** (radices sympatheticae g. ciliaris) arises in the cranium and enters the orbit through the sphenoidal fissure, either as an independent structure or jointly with the nasal or with the oculomotor nerve. As the sympathetic root (radix media), it enters the upper posterior angle of the ciliary ganglion (Fig. 1058), either alone or as a common trunk with the sensory root.

ff. The **branches to the pituitary body** consist of several tiny filaments which enter the substance of that body.

4. The **vertebral branches** consist of two or three filaments which pass backward, pierce the prevertebral muscles and are distributed to the bony and ligamentous structures of the upper portion of the vertebral column.

The Middle Cervical Ganglion.—The middle cervical ganglion (**g. cervicale medium**), a structure not infrequently absent, consists of one or two collections of nerve-cells situated posterior to the carotid sheath in the neighborhood of the inferior thyroid artery (Fig. 1131). It lies about the level of the sixth cervical vertebra and represents the fusion of two primitive cervical ganglia.

The **somatic branches** are: (1) the *gray rami communicantes* and (2) the *subclavian loop.*

1. The **gray rami communicantes** arise either from the ganglion or from its upper or lower association cord. They consist of two trunks which pass backward and join the anterior primary divisions of the fifth and sixth cervical nerves.

2. The **subclavian loop** (**ansa subclavia [Vieussenii]**) is a nerve, frequently double, which passes over the subclavian artery and joins the inferior cervical ganglion sending twigs (**plexus subclavius**) to the subclavian artery and its branches and to the phrenic nerve.

The **visceral branches** are: (1) the *thyroid plexus* and (2) the *middle cervical cardiac nerve.* In case of absence of the middle cervical ganglion, these branches arise from the interganglionic association cord between the superior and inferior ganglia.

1. The **thyroid plexus** (**plexus thyreoideus inferior**) consists of several fine inosculating twigs which accompany the inferior thyroid artery into the substance of the thyroid body.

2. The **middle cervical cardiac nerve** (**n. cardiacus medius**) (Fig. 1131) differs in its course on the two sides of the body. Descending in the neck, where it inosculates with the superior cervical cardiac and inferior laryngeal nerves, it passes, on the right side, either anterior or posterior to the subclavian artery, to the front of the trachea where it receives filaments of inosculation from the inferior laryngeal nerve. On the left side it enters the thorax between the common carotid and subclavian arteries. On both right and left sides it terminates posterior to the arch of the aorta by entering corresponding sides of the deep cardiac plexus.

Variations.—The gangliated cord, in the region of the middle ganglion, may lie posterior to the inferior thyroid artery or may be bifurcated, the artery lying between the two portions.

The Inferior Cervical Ganglion.—The inferior cervical ganglion (**g. cervicale inferius**) (Fig. 1079) is situated at the root of the neck, over the first costo-central articulation, between the neck of the first rib and the transverse process of the seventh cervical vertebra. In shape it is irregular, being flat, round or crescentic, and it is often fused with or only partially separated from the first thoracic ganglion. Situated in the external angle between the subclavian and vertebral arteries it is usually connected above with the middle ganglion by an association cord and by the subclavian loop, the former, passing posterior to the vertebral artery, but sometimes, especially on the left side, forming a nervous ring around that vessel.

The **somatic branches** consist of: (1) the *gray rami communicantes*, (2) the *subclavian loop* and (3) a *communicating branch to the inferior laryngeal nerve.*

1. The **gray rami communicantes** consist of two nonmedullated trunks which join the anterior primary divisions of the seventh and eighth cervical nerves.

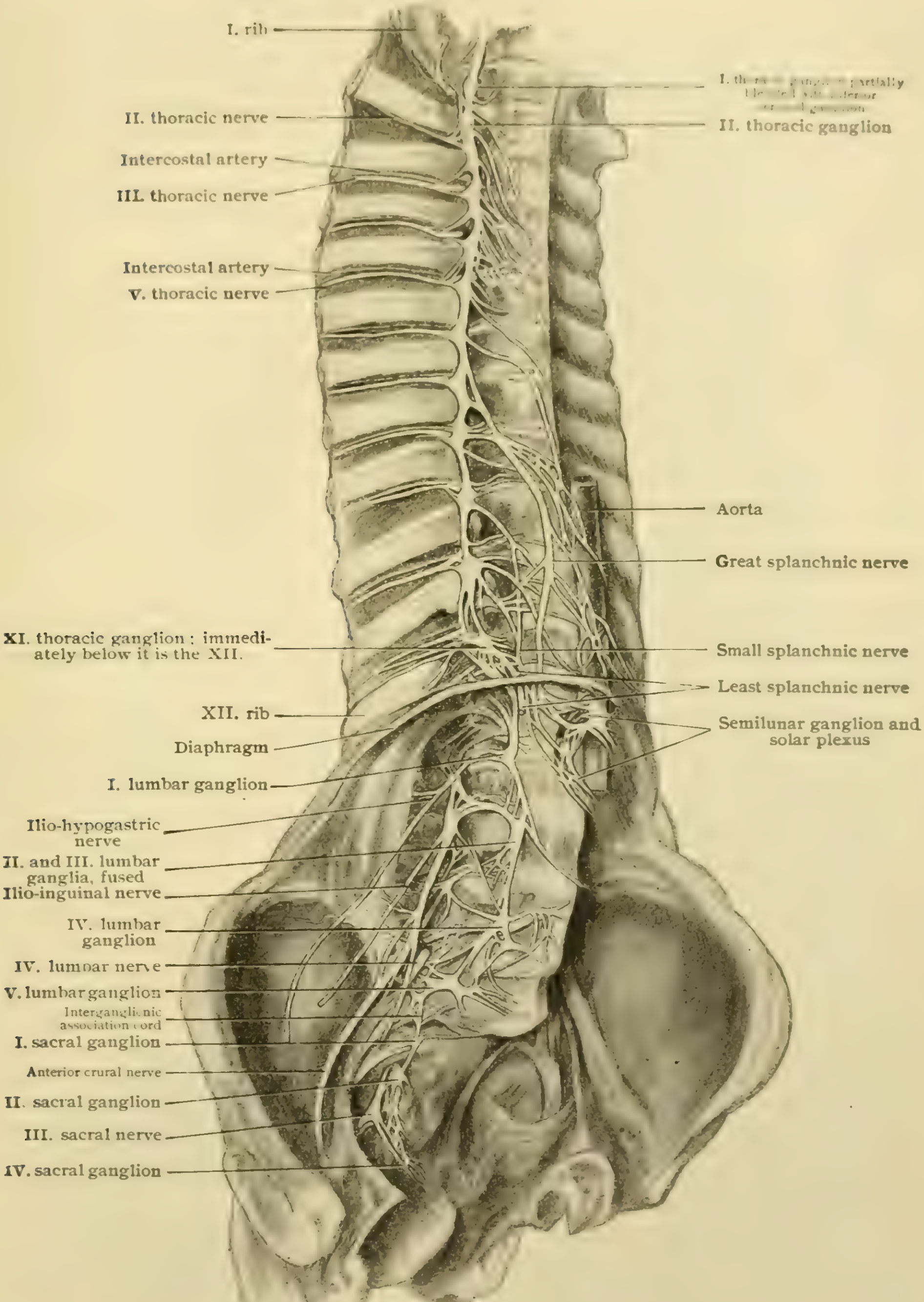
2. The **subclavian loop** (**ansa subclavia [Vieussenii]**) has already been described, as a branch of the middle cervical ganglion.

3. The **communicating branch to the inferior laryngeal nerve** frequently accompanies the inferior cervical cardiac nerve; it joins the inferior laryngeal posterior to the subclavian artery.

The **visceral branches** comprise: (1) the *vertebral plexus* and (2) the *inferior cervical cardiac nerve.*

1. The **vertebral plexus** (plexus vertebralis) is a closely woven net-work of fibres which follows the course and distribution of the vertebral artery in the neck and cranium.

FIG. 1133.



Dissection showing thoracic, lumbar and sacral portions of right gangliated cord and their branches.

2. The **inferior cervical cardiac nerve** (n. cardiacus inferior) (Fig. 1132), sometimes arising from the first thoracic ganglion, descends in the thorax posterior to

the subclavain artery, inosculates with the middle cervical cardiac and inferior laryngeal nerves and terminates in the deep cardiac plexus.

THE THORACIC PORTION OF THE GANGLIATED CORD.

The thoracic portion of the gangliated cord (**pars thoracalis systematis sympathetici**) consists of a series of eleven, twelve, ten or even fewer irregularly triangular, fusiform or oval ganglia (**gg. thoracalia**), situated lateral to the bodies of the thoracic vertebræ, covered by parietal pleura and interconnected by association cords which lie anterior to the intercostal blood-vessels (Fig. 1133). The largest of the ganglia is the first, which is situated at the mesial end of the first intercostal space and is not infrequently fused with the inferior cervical ganglion. The location of the thoracic ganglia corresponds usually to the heads of the ribs, the lowest being placed anterior to the head of the twelfth rib and at the upper margin of the twelfth thoracic vertebra.

A characteristic of the thoracic ganglia is the almost unvarying *presence of white rami communicantes*, all of the series, with the possible exception of the first, receiving these rami from the thoracic spinal nerves. They consist of an *upper* and a *lower* series, the former coming from the upper five nerves and coursing head-ward to enter and be distributed mainly by way of the cervico-cephalic portion of the gangliated cord; and the lower arising from the lower seven and being distributed to certain thoracic and abdominal structures. As elsewhere, so here from each of the ganglia is given off a gray ramus communicans to a thoracic spinal nerve.

The **somatic branches** of the thoracic portion of the gangliated cord are chiefly the gray rami communicantes. These arise from each of the thoracic ganglia and, in close proximity to the white rami, pass backward and join the anterior primary divisions of all the thoracic spinal nerves.

The **visceral branches** arise from the ganglia and their association cords and consist of gray splanchnic efferent and white splanchnic efferent and afferent fibres.

The **splanchnic afferent fibres** have no sympathetic connections, and consist merely of tracts which carry impulses from the splanchnic area through the thoracic and spinal ganglia to the posterior roots of the spinal thoracic nerves.

The **splanchnic efferent fibres**, after passing through the gangliated cord or its peripheral branches, form links with the cells of the collateral or terminal ganglia, from which nonmedullated axones are derived for the supply of various visceral or vascular structures. Those of the upper series are distributed mainly as branches of the cervical ganglia; while those of the lower series, from the sixth to the twelfth thoracic nerves inclusive, *in the thorax* supply the aorta and lungs with vasomotor fibres. *Below the thorax* their distribution is quite extensive, including, in conjunction with the vagus, viscero-inhibitory fibres for the stomach and intestine, motor fibres for a portion of the circular muscle of the rectum, vasomotor fibres for the abdominal aorta and its branches and secretory and sensory fibres for the abdominal viscera. The thoracic gangliated cord is peculiar in containing, along with the visceral fibres distributed by its splanchnic efferents, many efferents proceeding from the spinal cord destined for regions supplied by way of the limb nerves arising from the cervical and lumbo-sacral segments of the spinal cord. In order to provide gray rami at appropriate levels to join the spinal nerves the spinal efferents course both up and down in the gangliated cord beyond the thoracic region. In this manner the thoracic nerves, in addition to giving off the splanchnic efferents, provide vasomotor, pilomotor and secretory filaments for the greater part of the lower half of the body.

The **visceral branches** comprise: (1) the *pulmonary branches*, (2) the *aortic branches* and (3) the *splanchnic nerves*.

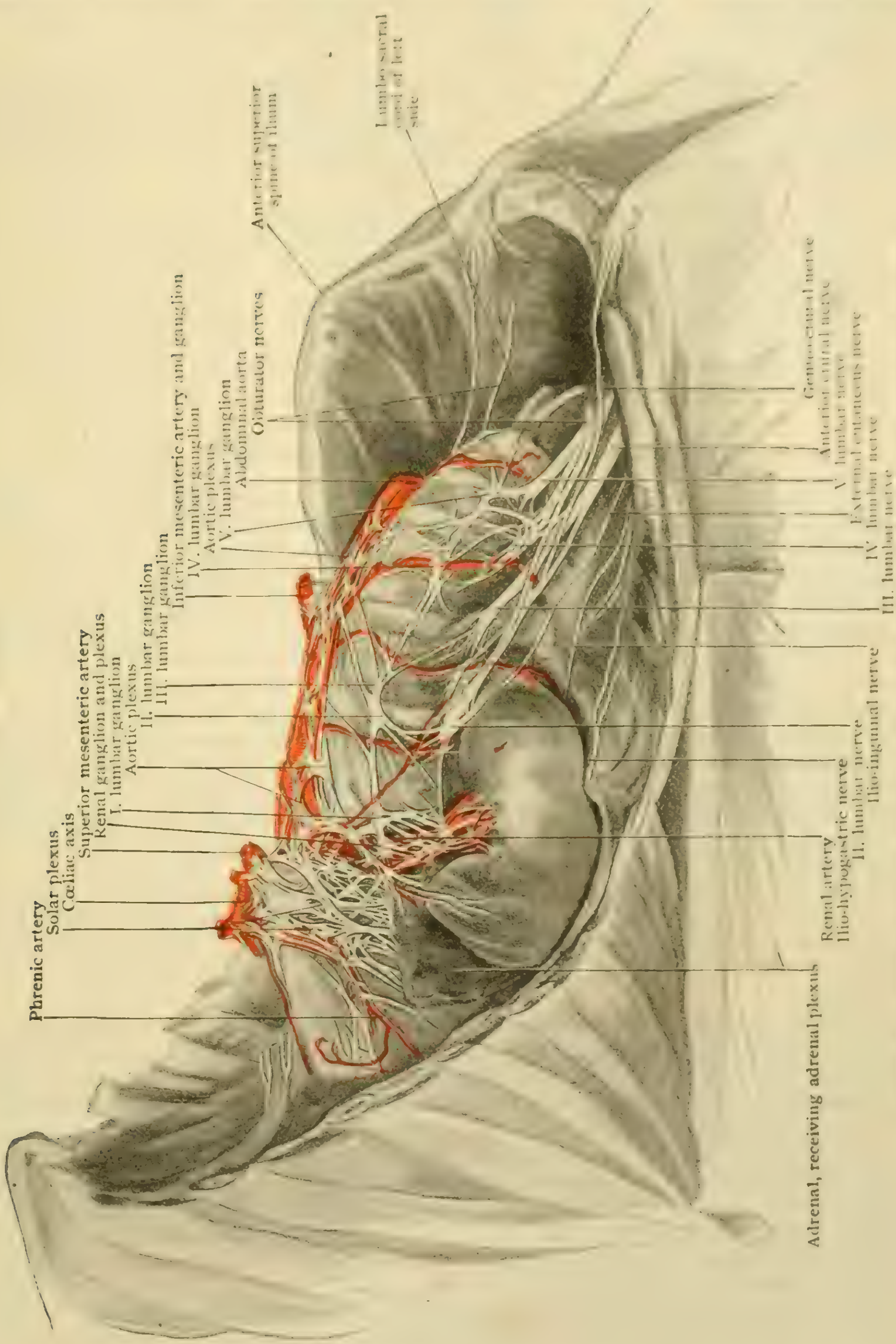
1. The **pulmonary branches** (**rr. pulmonales**) are derived from the second, third and fourth ganglia and proceed forward to join the posterior pulmonary plexus.

2. The **aortic branches** arise from the upper four or five ganglia and, after furnishing a few fine twigs to the vertebræ and their ligaments, inosculate around the thoracic aorta in the form of a fine plexus (**plexus aorticus thoracalis**).

3. The **splanchnic nerves** (**nn. splanchnici**) (Fig. 1133) are three trunks which arise from the lower part of the thoracic cord and are distributed to structures situated in the abdominal cavity.

The great splanchnic nerve (n. splanchnicus major) arises by a series of roots from the gangliated cord from the fifth to the ninth ganglia inclusive. Descending along the antero-lateral aspect of the vertebral column, this nerve pierces the crus of

FIG. 1134.



Dissection showing lumbar portion of gangliated cord and solar, aortic and renal sympathetic plexuses.

the diaphragm and enters the upper end of the semilunar ganglion, some of its fibres being traceable to the suprarenal body and the renal plexus. In the thoracic portion of its course is developed the *great splanchnic ganglion* (g. splanchnicum) from

which, as well as from the nerve itself, are given off filaments for the supply of the œsophagus, the thoracic aorta and the vertebræ. Sometimes in the thorax it is divided and forms a plexus with the small splanchnic and in this event several small ganglia are present. This nerve consists mainly (four-fifths according to Rüdinger) of medullated fibres, which are direct continuations of white rami from as far up as the third thoracic nerve or even higher.

The **small splanchnic nerve** (**n. splanchnicus minor**) arises from the ninth and tenth, or tenth and eleventh ganglia or from adjacent portions of interganglionic cords. Entering the abdomen by piercing the crus of the diaphragm either in association with or in close proximity to the great splanchnic, it terminates in that portion of the semilunar ganglion called the *aortico-renal ganglion.*

The **least splanchnic nerve** (**n. splanchnicus imus**) arises from the lowest of the thoracic ganglia and may receive a filament from the small splanchnic, from which it occasionally takes origin. Piercing the diaphragm in company with the gangliated cord it terminates in the renal plexus.

A **fourth splanchnic nerve** is rarely present. It is described by Wrisberg as having been found in eight cadavers out of a large number examined. It is formed by filaments from the cardiac nerves, aided by twigs from the lower cervical and upper thoracic ganglia.

THE LUMBAR PORTION OF THE GANGLIATED CORD.

The lumbar portion of the gangliated cord (**pars abdominalis systematis sympathetici**) (Fig. 1134) consists usually of four small oval ganglia connected by association cords. There may be a decided increase in the number of the ganglia, as many as eight having been found, and, on the other hand, occasionally there are fewer than four, there being under these circumstances a compensatory increase in the size of the ganglia present. The lumbar portion of the sympathetic lies nearer the median line than does the thoracic, the cords being placed anterior to the bodies of the lumbar vertebræ and the lumbar vessels, along the mesial border of the psoas magnus, on the left side being partially concealed by the aorta and on the right by the inferior vena cava. It is connected with the thoracic portion by a small association cord, which passes either through or posterior to the diaphragm, and with the sacral portion by a cord which descends behind the common iliac artery. White rami communicantes are received from the first, the second and sometimes the third lumbar nerve, additional white fibres being derived from the lower thoracic nerves by way of the gangliated cord.

The **somatic branches** comprise the peripheral distribution of the *gray rami communicantes.* These are the longest to be found in the body, on account of the distance between the ganglia and the intervertebral foramina. They accompany the lumbar vessels and pass beneath the fibrous arches from which the psoas magnus takes origin.

1. The **white rami communicantes** are derived from the upper two or three lumbar nerves and join the upper ganglia or the adjacent portion of the interganglionic cord. They contain splanchnic efferent and afferent fibres, which continue downward the distribution of the thoracic portion of the gangliated cord, including vasomotor and secretory fibres for the lower extremities, pilomotor fibres, vasomotor fibres for the abdominal vessels, motor fibres for the circular musculature of the rectum and inhibitory fibres for the longitudinal muscle of the rectum. Fibres peculiar to the lumbar region include vasomotor nerves of the penis and motor fibres for the bladder and uterus, those to the bladder supplying the sphincter as well as the circular and longitudinal muscle-fibres, those to the last-mentioned group being inhibitory.

2. The **gray rami communicantes** are irregular in number and arrangement, sometimes a single one dividing and joining two lumbar nerves and sometimes two to five passing to a single spinal nerve.

The **visceral branches** vary considerably in their distribution, some joining the hypogastric plexus (**plexus hypogastricus**), others the aortic plexus (**plexus aorticus abdominalis**) and still others supplying the vertebræ and their ligaments.

THE SACRAL PORTION OF THE GANGLIATED CORD.

The sacral portion of the gangliated cord (pars pelvina systematis sympathetici) consists of four ganglia interconnected by association cords, there being a considerable degree of variation in both the number and the size of the ganglia (Fig. 1133). Lying anterior to the sacrum and internal to the anterior sacral foramina, it is connected above with the lumbar portion by a single or double association cord which lies posterior to the common iliac artery, and below it gradually approaches the median line and is united in front of the coccyx with its fellow of the opposite side by a loop or fine plexus in which is situated the single **coccygeal ganglion** or **ganglion impar.**

While this portion of the gangliated cord receives no white rami communicantes, in the sense of trunks passing from the sacral spinal nerves to the sacral ganglia, the visceral branches of the pudendal plexus pass directly to the pelvic plexus without traversing ganglia, and are considered as being homologous with white rami. In addition to these, white fibres reach the sacral from the lumbar portion of the gangliated cord.

The **somatic branches** are the gray rami communicantes. They arise from the sacral ganglia and pass dorsally to join the anterior primary divisions of the sacral and coccygeal spinal nerves.

The **visceral branches** are distributed through the medium of the **pelvic plexus** (page 1374) and furnish motor fibres to the longitudinal and inhibitory fibres to the circular musculature of the rectum, the chief motor fibres to the bladder (probably to the longitudinal muscular fibres), motor fibres to the uterus, the *nervi erigentes* or vaso-dilators of the penis and secretory fibres to the prostate gland.

Additional strands, the **parietal branches** unite and ramify, anterior to the sacrum, with similar twigs from the opposite side and furnish filaments to the sacrum and coccyx and their ligaments, and to the coccygeal body.

THE PLEXUSES OF THE SYMPATHETIC NERVES.

The tendency of the sympathetic nerves to form intricate and elaborate plexuses (**plexus sympathetici**) is a marked feature of this portion of the nervous system. They lie, in the main, anterior to the plane of the gangliated cord and consist of fibres alone or of fibres and ganglia, from which smaller plexuses or branches pass to the viscera. Some of them are of sufficient importance, size and individuality to merit separate descriptions; such are the *cardiac*, the *pulmonary*, the *œsophageal*, the *solar* and the *pelvic.* The pulmonary and œsophageal plexuses have been described in connection with the vagus nerve (page 1272).

The Cardiac Plexus.

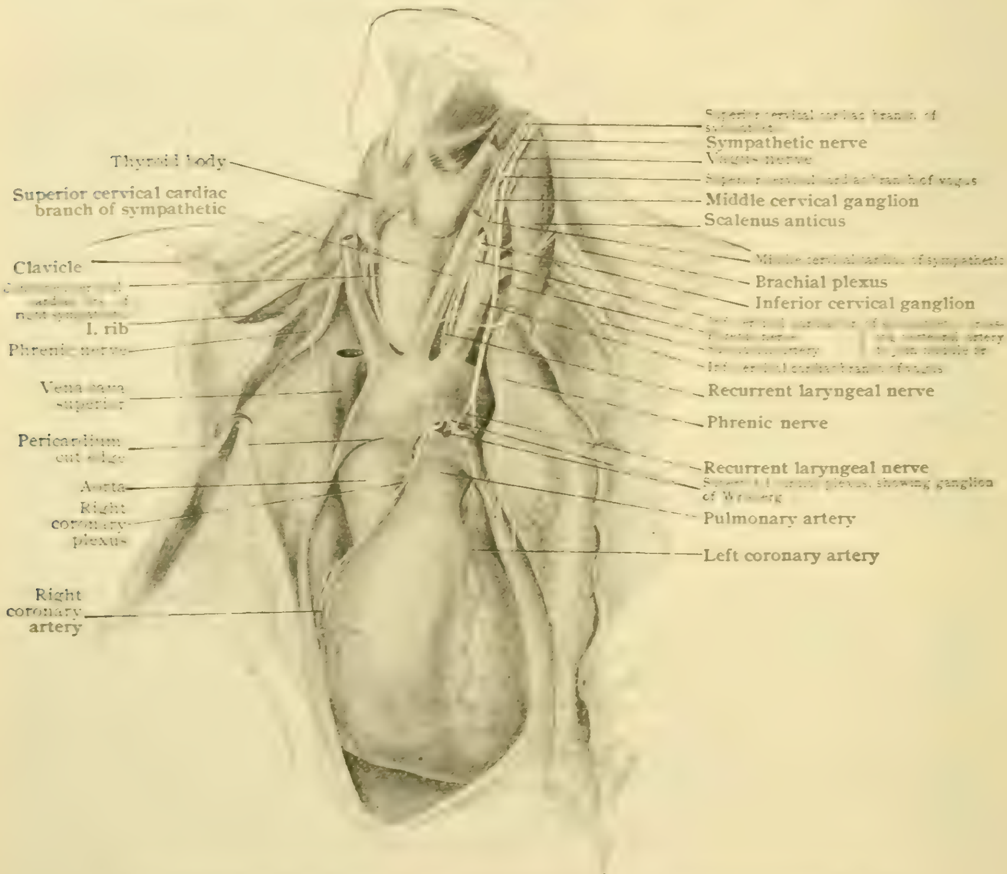
The cardiac plexus (**plexus cardiacus**) consists of an interlacement of nerve-fibres, containing one well-marked ganglion, to which accessions are brought by the vagus and sympathetic nerves and from which fibres are furnished to the heart and, to a slight degree, the lungs. It comprises two portions: (1) the *superficial cardiac plexus* and (2) the *deep cardiac plexus.*

1. The **superficial cardiac plexus** (Fig. 1135) is much the smaller of the two and consists of a fine inosculation of nerve-fibres in the meshes of which is contained a small ganglion, the *ganglion of Wrisberg* (**g. cardiacum [Wrisbergi]**). It is situated in the concavity of the arch of the aorta, between the obliterated ductus arteriosus and the right pulmonary artery. Tributary to it are the superior cervical cardiac branch of the left gangliated cord and the inferior cervical cardiac branch of the left vagus, whilst its fibres of distribution contribute to (*a*) the right coronary plexus, (*b*) the left half of the deep cardiac plexus and, along the left pulmonary artery, (*c*) the left anterior pulmonary plexus.

2. The **deep cardiac plexus** (Fig. 1135), considerably larger than the superficial, is located above the bifurcation of the pulmonary artery, posterior to the arch of the aorta and anterior to the lower end of the trachea. It comprises two

distinct portions, a right and a left, united by numerous fibres around the lower end of the trachea. The **right portion** receives as tributaries all of the cardiac branches of the sympathetic, vagus and inferior laryngeal nerves of the right side. The **left portion** receives all of the cardiac branches of the left vagus and sympathetic nerves, except the two which enter the superficial plexus (the superior cervical cardiac branch of the left gangliated cord and the inferior cervical branch of the left vagus), with the addition of filaments from the left inferior laryngeal nerve and from the superficial **cardiac plexus.**

FIG. 1135.



Dissection showing constituents of superficial cardiac plexus, other cardiac nerves and right coronary plexus.

From the right portion of the plexus arises the **right** or **anterior coronary plexus** (**plexus coronarius cordis anterior**), to which fibres are sent from the superficial plexus. This plexus reaches the heart by coursing along the ascending aorta and then follows the right coronary artery, in whose course it distributes fibres to adjacent portions of the heart. Other branches from the right portion join the superficial cardiac plexus and the right anterior pulmonary plexus.

From the left portion originates the **left** or **posterior coronary plexus** (**plexus coronarius cordis posterior**) which, reinforced by fibres from the superficial plexus, follows the course and distribution of the corresponding artery. The left portion contributes filaments to the superficial cardiac and left anterior pulmonary plexuses.

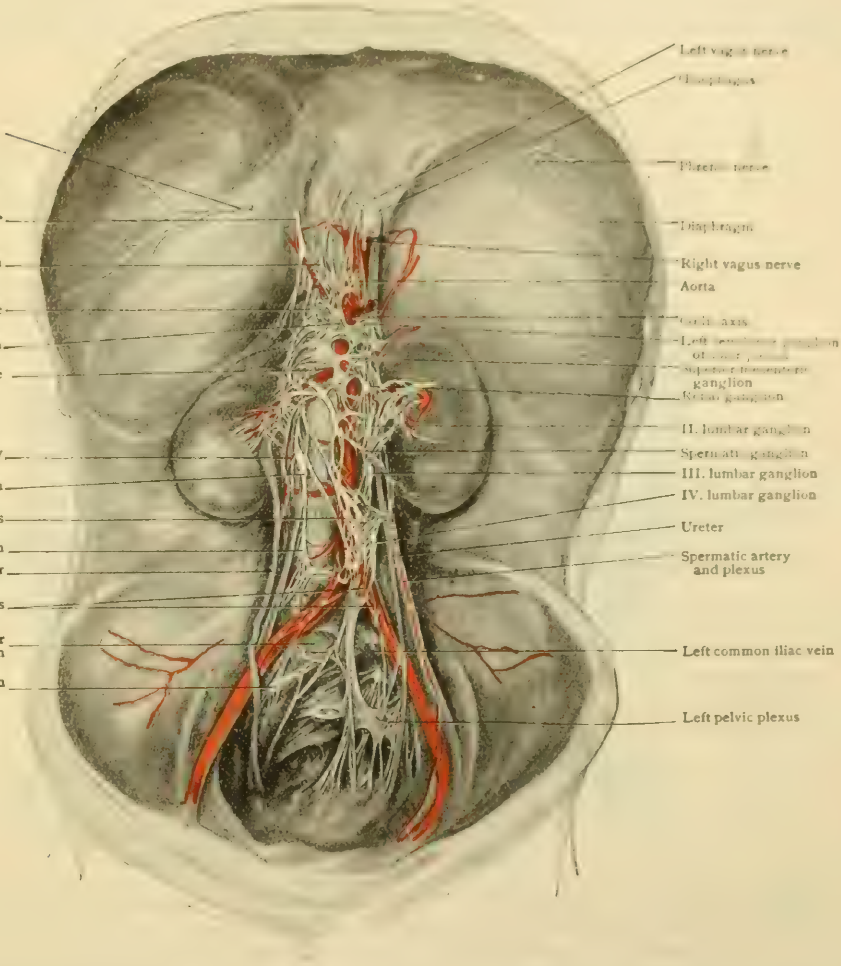
THE SOLAR PLEXUS.

The abdominal and pelvic cavities are innervated by the solar, hypogastric and pelvic plexuses, composed of the visceral branches of the lower thoracic, lumbar and upper sacral portions of the gangliated cord, in conjunction with the central nervous

axis by means of the rami communicantes of the lower thoracic and upper lumbar nerves and the visceral branches of the pudendal plexus.

The solar or epigastric plexus (Fig. 1136), the largest of the series, is situated in the upper abdominal region, posterior to the stomach, anterior to the aorta and the crura of the diaphragm, superior to the pancreas, between the suprarenal bodies and around the origins of the cœliac axis and the superior mesenteric artery. It is continuous above with the diaphragmatic plexus, laterally with the suprarenal and

FIG. 1136.



Dissection of abdominal sympathetic nerves, showing solar, hypogastric and secondary plexuses.

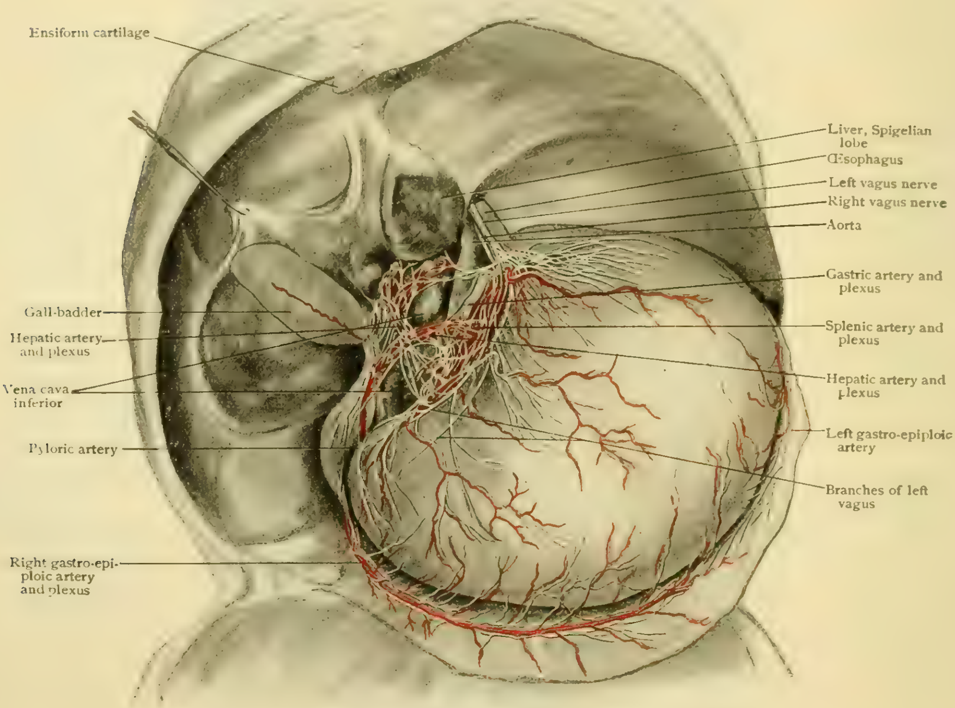
renal plexuses, below with the superior mesenteric and aortic plexuses and, by means of the aortic and hypogastric plexuses, with the two pelvic plexuses. Contributory to it are the right vagus and the great and small splanchnic nerves. The fully formed plexus consists of two portions: (1) the *semilunar ganglia* and (2) the *cœliac plexus*.

1. The **semilunar ganglia** (gg. coeliaca) (Fig. 1136), the largest of the ganglionic elements in the solar plexus, are situated upon the crura of the diaphragm at the superior and lateral portions of the plexus, partly overlapped by the suprarenal bodies and separated from each other by the cœliac axis and the superior mesenteric artery; the right one is partially covered by the superior vena cava and the two are

connected by cords which pass transversely above and below the root of the cœliac axis. The upper end of each is expanded and receives the termination of the great splanchnic nerve, while the lower portion, the **aortico-renal ganglion,** is partially detached and receives the small splanchnic nerve. A third portion, located below and to the right of the root of the superior mesenteric artery, is called the **superior mesenteric ganglion** (g. mesentericum superius). From each semilunar ganglion branches emerge in all directions to join those plexuses which are continuous with the solar.

2. The **cœliac plexus** (plexus coeliacus) embraces the cœliac axis and consists of a dense felt-work of nerve-fibres, in which are embedded numerous small ganglia, and which is joined by branches from both semilunar ganglia and from the right

FIG. 1137.



Dissection showing gastric and hepatic plexuses.

vagus. Inferiorly it is continued into the superior mesenteric and aortic plexuses and from it arise the coronary, hepatic and splenic plexuses.

The **gastric plexus** (plexus gastricus superior) accompanies the gastric artery along the lesser curvature of the stomach, inosculates with both vagus nerves and distributes branches which run for a short distance beneath the peritoneum and then enter and supply the deeper coats of the stomach.

The **hepatic plexus** (plexus hepaticus) traverses the lesser omentum in company with the bile duct, the hepatic artery and the portal vein and, after inosculating with fibres of the left vagus, enters the liver, in which it ramifies. In addition to its terminal distribution it contributes filaments to the right suprarenal plexus and furnishes offshoots which follow the collateral branches of the hepatic artery, supplying the areas to which these arteries are distributed.

The **splenic plexus** (plexus lienalis), which surrounds the splenic artery, receives accessions from the left semilunar ganglion and the right vagus and enters the spleen. Branches of the plexus accompany the branches of the splenic artery and are distributed similarly.

The **diaphragmatic** or **phrenic plexus** (plexus phrenicus) is derived from the upper portion of the semilunar ganglion and accompanies the phrenic branch of the abdominal aorta to the diaphragm, the right being larger than the left. After supplying some filaments to the suprarenal body, it enters the musculature of the diaphragm and there unites with the phrenic nerve from the cervical spinal plexus. At the point of inosculation, on the right side only, near the suprarenal body and on the under surface of the diaphragm, is a small ganglion called the **phrenic ganglion** (g. phrenicum). From it are given off branches to the suprarenal body, the inferior vena cava and the hepatic plexus.

The **suprarenal plexus** (plexus suprarenalis) arises from the lateral aspect of the semilunar ganglion and is joined by filaments from the diaphragmatic and renal

FIG. 1138.

Dissection showing gastric, hepatic and splenic plexuses; stomach has been turned up and part of pancreas removed.

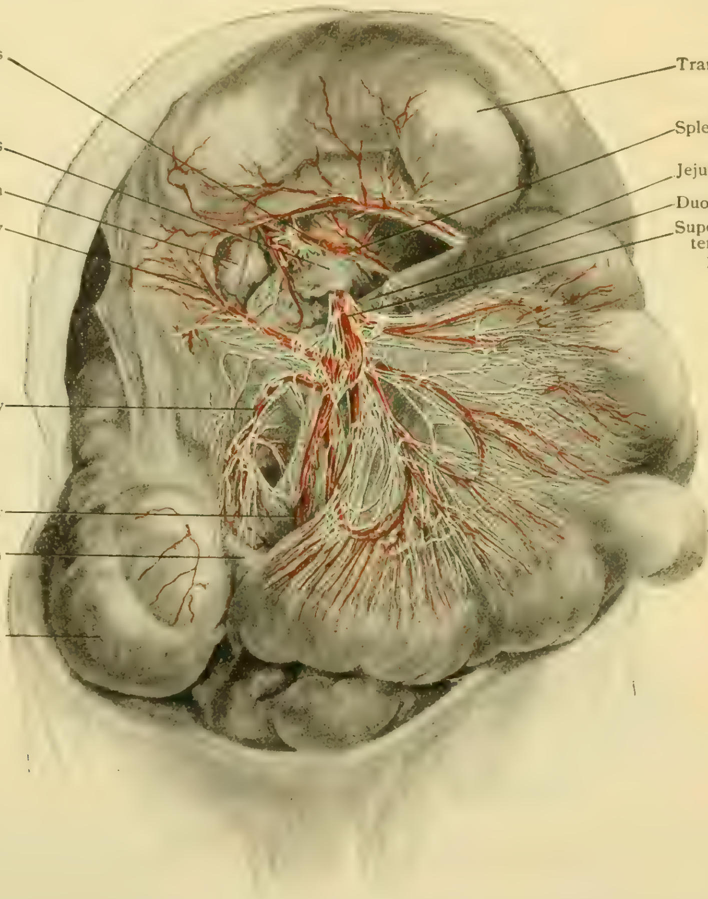
plexuses. It consists mainly of medullated fibres and, while very short, is made up of a number of filaments and is of considerable size. Numerous tiny ganglia are scattered throughout the meshes of this plexus.

The **renal plexus** (plexus renalis) is derived mainly from the aortico-renal ganglion, additional fibres being contributed by the smallest splanchnic nerve, sometimes by the small splanchnic, and by the aortic and suprarenal plexuses; there is occasionally present a twig from the first lumbar ganglion. Entering the hilum of the kidney with the renal artery, the plexus splits up and ramifies in the renal substance. In its course along the artery a number of ganglia of varying size, called the **renal ganglia**, are found. In addition to supplying the kidney, filaments are furnished to the spermatic plexus and to the ureter, and on the right side to the inferior vena cava.

The **spermatic plexus** (plexus spermaticus) follows the course of the spermatic artery through the abdomen, inguinal canal and scrotum, inosculating with filaments which arise in the pelvis and accompany the vas deferens and its artery to the scrotum. It is derived from the renal and aortic plexuses, a small **spermatic ganglion** being situated at the point of origin of the fibres contributed by the aortic plexus.

The **ovarian plexus** (plexus ovaricus), arising similarly to the spermatic, accompanies the ovarian artery and is distributed to the ovary, the oviduct, the broad ligament and the uterus. In the broad ligament it inosculates with those pelvic fibres which constitute the uterine plexus.

FIG. 1139.



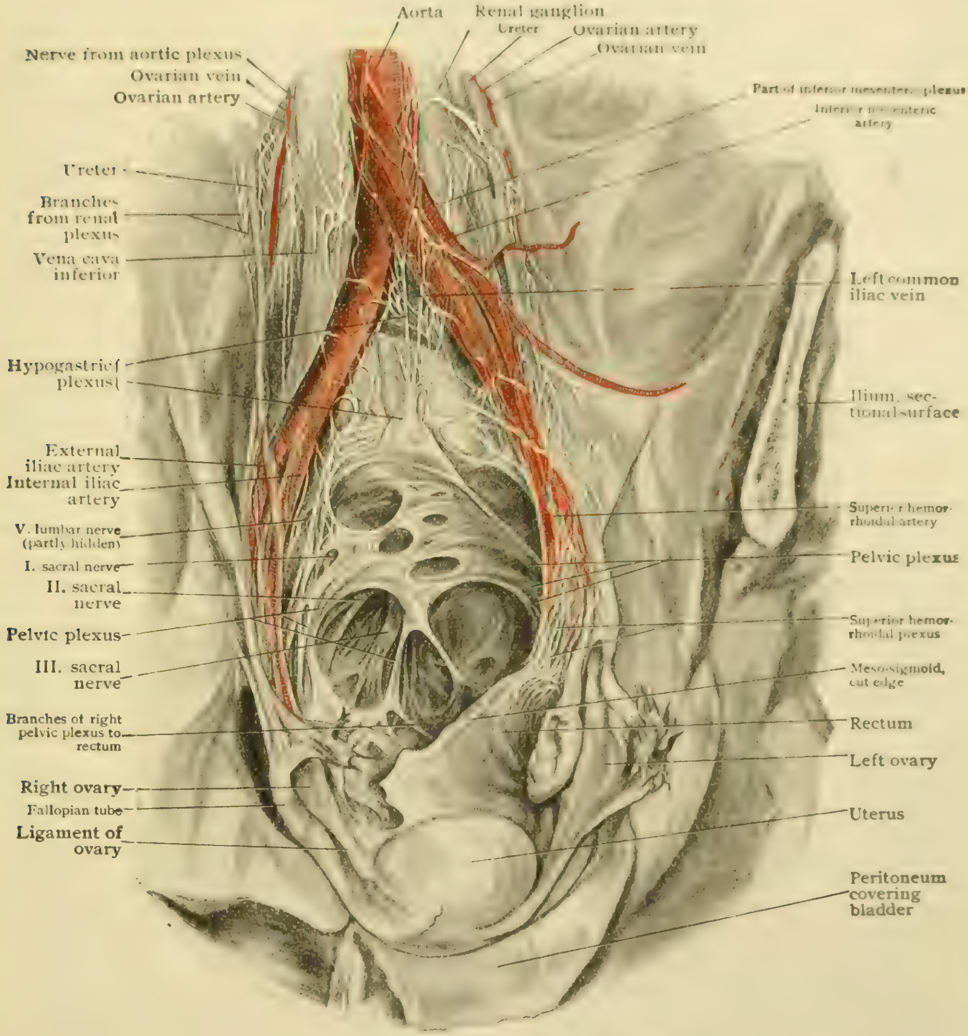
Dissection showing hepatic and superior mesenteric plexuses; transverse colon has been turned up.

The **superior mesenteric plexus** (plexus mesentericus superior) (Fig. 1139), firm in texture and containing a large admixture of medullated fibres, is continuous with the cœliac plexus above and with the aortic below. Its fibres are derived from the semilunar ganglia, the cœliac plexus and the right vagus. Situated in the root of the plexus and lying below and to the right of the origin of the superior mesenteric artery is the **superior mesenteric ganglion** (g. mesentericum superius), from which a number of the fibres of the plexus arise. Accompanying the superior mesenteric artery, the plexus gives off subdivisions which correspond to and follow the course of the branches of that artery, supplying filaments to the small intestine, the cœcum, the vermiform appendix and the ascending and transverse colons. As

the fibres approach the distal edge of the mesentery some of them leave the vessels and form minute independent plexuses from which filaments pass to the gut.

The **aortic plexus** (plexus aorticus abdominalis) (Fig. 1136) is the direct downward extension of the solar. Embracing the aorta, it extends from the origin of the superior mesenteric artery above to that of the inferior mesenteric below, and is connected with the semilunar ganglia and with the renal and superior mesenteric plexuses superiorly and with the hypogastric inferiorly. It consists of a pair of

FIG. 1140.



Dissection showing hypogastric and pelvic plexuses.

symmetrically placed nerve trunks situated at the sides of the aorta and connected with each other by several branches which lie anterior to that vessel ; filaments from the lumbar ganglia join the main cords of the plexus. It gives off the inferior mesenteric plexus, sends contributions to the suprarenal, renal and spermatic or ovarian, supplies filaments to the aorta and inferior vena cava and terminates in the hypogastric plexus.

The **inferior mesenteric plexus** (plexus mesentericus inferior) is derived from the left portion of the aortic plexus and follows the course and distribution of the artery for which it is named. Situated a short distance beyond its origin is the small **inferior mesenteric ganglion.** From this plexus branches are

distributed to the descending and sigmoid colons and to the upper portion of the rectum.

The **hypogastric plexus** (**plexus hypogastricus**) (Fig. 1140), the continuation of the aortic, lies on the posterior wall of the pelvis in the angle between the common iliac arteries, and enclosed in a firm investment of fibrous tissue. In addition to the fibres derived from the aortic plexus, others are contributed by the lumbar ganglia, and the resulting intricate interlacement, in which there are no ganglia, constitutes the hypogastric plexus. It supplies the pelvic contents and at its lower end divides into the two pelvic plexuses.

The **pelvic plexuses** (**plexus hypogastrici inferiores**), (Fig. 1140) the terminal divisions of the hypogastric, are situated lateral to the rectum and to the vagina in the female. They comprise fibres derived from the hypogastric plexus and from the upper part of the sacral portion of the gangliated cord, aided by the *visceral branches of the pudendal plexus*, all of these forming an elaborate net-work, in which are dotted numerous small ganglia. The completed structure follows the course of the internal iliac artery, around whose branches it sends derivatives for the supply of the pelvic contents.

The **hemorrhoidal plexus** (**plexus hemorrhoidalis medius**) arises from the upper portion of the pelvic plexus and after inosculating with the superior hemorrhoidal branches (**nn. hemorrhoidales superiores**) of the inferior mesenteric plexus, are distributed to the rectum.

The **vesical plexus** (**plexus vesicalis**) consists of branches of the pelvic which accompany the vesical arteries to the lateral and inferior portions of the bladder, after reaching which they leave the vessels and split into small twigs for the supply of the bladder, some filaments going to the ureter, the vas deferens and the seminal vesicle.

The **prostatic plexus** (**plexus prostaticus**) comprises a number of nerves of considerable size and is situated between the lateral aspect of the prostate gland and the mesial surface of the levator ani muscle. After furnishing twigs to the prostatic urethra, the neck of the bladder and the seminal vesicle, it continues forward as the *cavernous plexus.*

The **cavernous plexus** (**plexus cavernosus penis**) extends forward through the triangular ligament and the compressor urethræ muscle to the dorsum of the base of the penis, where it receives some communicating filaments from the pudic nerve. After supplying branches to the apex of the prostate gland and the membranous urethra, the plexus terminates by breaking up into (1) the *small* and (2) *large cavernous nerves* of the penis.

1. The **small cavernous nerves** (**nn. cavernosi penis minores**) pierce the fibrous envelope of the crus penis and end in filaments which supply the erectile tissue of the corpus cavernosum.

2. The **large cavernous nerve** (**n. cavernosus penis major**), consisting mainly of medullated fibres, passes directly along the dorsum of the penis, giving off filaments which enter the substance of the corpus cavernosum. At about the middle of the body of the penis it inosculates with the dorsal nerve of the penis, both of these nerves sending twigs to the corpus spongiosum.

The **utero-vaginal plexus** (**plexus uterovaginalis**) corresponds to the prostatic plexus of the male and consists of two portions : (1) the *uterine plexus* and (2) the *vaginal plexus.*

1. The **uterine plexus** (**plexus uterinus**) is derived from the pelvic plexus and is supplemented in its distribution by the visceral branches from the pudendal plexus. These fibres accompany the uterine vessels along the side of the uterus, most of them entering the cervix and the lower portion of the body of the uterus. They inosculate with fibres from the ovarian plexus and in their meshes are found many small ganglia, a collection of which is located near the cervix uteri and is called the **ganglion cervicale.**

2. The **vaginal plexus** (**plexus vaginalis**) arises from the lower part of the pelvic and comprises mainly fibres derived from the visceral branches of the pudendal plexus. It supplies the vagina and the urethra and continues forward as the cavernous plexus of the clitoris (**plexus cavernosus clitoridis**).

Practical Considerations.—The *cervical sympathetic* may be injured by deep wounds of the neck, or may be compressed by tumors, abscesses or aneurisms. It supplies motor fibres to the involuntary muscles of the orbit and eyelids, vasomotor fibres to the face, neck and head, dilator fibres to the pupil, accelerator fibres to the heart and secretory fibres to the salivary glands. If it is irritated, some or all of the following symptoms will be present: the palpebral fissure will open wider, the eyes will be protruded, the skin of the face and neck will be pale and cold, the pupils dilated, and the sweat, nasal secretion and saliva diminished. Section or destruction of the cervical sympathetic will give the opposite symptoms.

The cervical sympathetic has been removed for epilepsy, glaucoma and exophthalmic goitre. The greatest success has been obtained in the last condition, especially by Jonnesco, who advises this procedure in hysteria, chorea, and tumors of the brain, as well as in the above-mentioned conditions. It may be excised through an incision anterior to the sterno-mastoid, as it lies posterior to the carotid sheath on the prevertebral fascia. The superior cervical ganglion is the largest and lies opposite the transverse processes of the second and third vertebræ. Branches of it go upward along the external and internal carotid arteries, the ascending branch passing along the internal carotid artery through its bony canal in the base of the skull to form the carotid and cavernous plexuses, both of which are really parts of one plexus arranged around this artery. Other branches communicate with the cranial nerves, the pharyngeal nerves and the superficial cervical cardiac nerve. The middle cervical ganglion is the smallest, lies on the inferior thyroid artery opposite the sixth cervical vertebra and is in danger in the ligation of that artery. The inferior ganglion, intermediate in size between the other two, lies in a depression between the neck of the first rib and the transverse process of the seventh cervical vertebra.

The branches of the upper four or five *thoracic ganglia* of the sympathetic enter into the supply of the thoracic viscera, but the branches of the lower seven or eight form the splanchnic nerves and go to the supply of the abdominal viscera through the solar plexus and its extensions into other sympathetic plexuses of the abdomen. It is of interest and importance to observe that those intercostal nerves corresponding in their origin from the spinal cord with the ganglia giving off the splanchnics, together with the first two lumbar nerves, the ilio-hypogastric and ilio-inguinal, supply the abdominal wall with motor and sensory branches. In this way the same segments of the spinal cord supply the abdominal viscera as well as the skin and muscles over them. A similar arrangement of the nerves is seen in the joints, where the same nerves supply the skin covering the joint, the muscles which move it, and the joint structures. As a result of this, when necessary, all parts of the joint act in sympathy. In an inflammation of the joint the skin becomes sensitive, tending to ward off interference, and the muscles become rigid, preventing motion and favoring rest. In a similar manner the abdominal muscles become rigid to protect inflamed viscera underneath, the muscles of one side only if the inflammation is localized to one side, but the muscles of both sides if a general peritonitis is present.

DEVELOPMENT OF THE PERIPHERAL NERVES.

The manner in which the nerve-fibres composing the peripheral nervous system develop from the primary cells, the neuroblasts, has been indicated in the previous sketch of their histogenesis given on page 1011. It remains, therefore, to describe briefly at this place the more important features of their morphogenesis. The fundamental fact has been repeatedly emphasized, that efferent or motor fibres are outgrowths from neurones situated within the cerebro-spinal axis, whilst all afferent or sensory fibres arise from cells placed outside this axis and within the ganglia located along the course of the nerves. It is evident, furthermore, that the efferent constituents of the peripheral nerves have their nuclei of origin within the spinal cord or brain and grow outward, as axones, to their destinations. The afferent fibres, on the other hand, proceed in both directions, the axones early growing centrally to join the nervous axis, hence, having usually a short course, being represented by the entering sensory roots. The dendrites grow in the opposite direction and contribute the sensory fibres that extend often to remote parts of the body. Whilst in the lowest vertebrates, the amphioxus and the cyclostomes, the ventral and dorsal roots of the spinal nerves remain distinct, in the higher types they join to form the mixed nerve, which typically divides into the anterior, posterior and

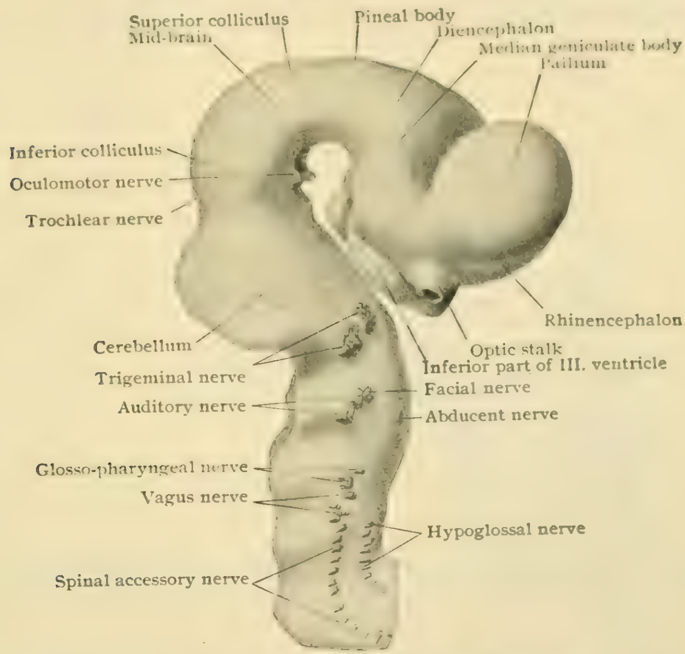
visceral divisions. Such typical division, however, is displayed only by those spinal nerves distributed to that part of the trunk in which the primary segmentation is retained, namely, the thoracic region, where the skeletal muscular, and vascular segments, as well as the nerves, retain their identity. In the other parts of the spinal series, the cervical and the lumbo-sacral, where provision is made for the supply of the highly differentiated musculature of the extremities from a number of cord-segments, the nerves early unite to form plexuses from which the limb-trunks grow out, an arrangement well adapted for the distribution of fibres from different sources without undue multiplication of nervous paths. Concerning the factors which guide the young nerve to its destination with such remarkable constancy, nothing is known, but it may be assumed that these are probably influences of a physical character, the developing nerve taking the path offering least resistance. The visceral division of the spinal nerve, to which reference has been made, corresponds to the white ramus communicans given off by certain of the thoracic and lumbo-sacral nerves. These splanchnic fibres differ from the somatic efferent ones in taking their origin from cells which occupy a more lateral position within the gray matter of the spinal cord than do the root-cells giving rise to the motor fibres destined for the skeletal muscles. Whilst the great majority of the splanchnic fibres reach the ramus of communication by way of the anterior root, some few perhaps traverse the posterior or sensory root and its ganglion before continuing their course to the sympathetic. The sensory fibres described within the anterior roots of the spinal nerves are not actual constituents of these roots, which are exclusively motor, but recurrent meningeal twigs destined for the membranes of the cord.

The Cranial Nerves.—From the preceding account of these nerves, it is evident that the optic nerve differs morphologically widely from an ordinary nerve, since it may be regarded as a modified outlying portion of the brain. Its development may be omitted, therefore, from this series and appropriately considered in connection with the development of the eye (page 1482). There is sufficient reason, as will appear later, for regarding the hypoglossal nerve as a cranially displaced member of the spinal series. Of the remaining nerves, only the olfactory and auditory are purely sensory ; the third, fourth, sixth and eleventh are exclusively motor ; and the fifth, seventh, ninth and tenth are mixed, the motor strands taking origin from the neurones within the brain-stem, while the sensory ones are derivations from the neurones lying within the ganglia connected with the afferent fibres. Although at first sight the trigeminus closely corresponds to a spinal nerve in the possession of a gangliated sensory and a motor root, critical examination of the origin of its motor fibres discloses an important difference, namely that they arise from the lateral nuclei and not from the mesial, which correspond to collections of ventral root-cells. A similar difference also appears between the efferent trigeminal fibres and those of the eye-muscle nerves, the latter arising from groups of root-cells occupying a position close to the mid-line. In order to appreciate the significance of this difference, reference must be made to the primary division of the musculature of the head already referred to in connection with the grouping of the muscles (page 472). It was there pointed out that it may be assumed that the segmented condition of the trunk musculature, as expressed by the metameres, is continued into the cephalic region but with subsequent suppression of the middle members of the possible nine or ten segments which constituted the original quota of head-metameres. Of those persisting two groups are recognized—one including the first three metameres, giving rise to the ocular muscles and being supplied by the third, fourth and sixth nerves ; the other including the last three or four, producing the tongue-muscles, and being supplied by the twelfth nerve. To these groups of cephalic metameres is added a third, the branchiomeres, which are regarded as representing a supplementary series connected with the branchial arches and not present in the trunk. The branchiomeres receive the mixed cranial nerves, whose motor filaments supply muscular masses surrounding the visceral tubes (digestive and respiratory), and arise from the lateral motor nuclei. It follows that none of the cranial nerves contain fibres from all these sources, in the case of the fifth, seventh, ninth and tenth, the fibres being derived from the lateral motor and the sensory nuclei, and in the case of the third, fourth and sixth, from the mesial (ventral) nuclei alone. From the primary conditions, as revealed by studies on the lower vertebrates, it is probable that the dorsal fibres also are by no means of similar morphological value, since some represent a somatic sensory system, as those distributed to the integument, and others belong to a visceral sensory one, as those distributed to the walls of the mouth, pharynx and larynx. Following the principle already emphasized, the motor fibres of the cranial nerves grow from the brain outward, while the sensory ones extend centrally from the ganglia of the nerves associated with the brain. The cranial and spinal nerves appear on the surface of the neural tube at a very early period, their presence being conspicuous by the end of the fourth week (Fig. 1141).

The **olfactory nerve** is developed in connection with the epithelial lining of the primary olfactory pit (page 1429). As early as the end of the first fœtal month, in the human embryo, cells corresponding to neuroblasts appear in the anlage of the olfactory organ. From these elements processes soon grow brainward, nucleated tracts indicating the formation of the later olfactory fibres. The cell-bodies of the young neurone migrate so that for a time their position

is no longer within the primary epithelium, but deeper and within a cell aggregation known as the *olfactory ganglion*. The neurones, however, retain connection with the olfactory epithelium by means of their peripherally directed processes, which correspond to dendrites, and with the brain by means of their axones. With the thickening of the olfactory epithelium which subsequently occurs, the peripheral fibres and their nuclei comes to lie entirely within the epithelial stratum and persist as the olfactory cells, whose centrally directed processes form the olfactory filaments that end as arborizations within the characteristic olfactory glomeruli. The first cranial nerve is peculiar in the superficial position of its cell-bodies and in the extreme shortness of its dendrites, which are represented by the rod-like fibres of microscopic length extending from the cell-bodies toward the free surface of the olfactory mucous membrane. This superficial position of the olfactory neurones is regarded as an unusual persistence of the primary condition of all sensory elements and as evidence of the archaic nature of the olfactory nerves.

FIG. 1141



Reconstruction of brain of human embryo of four and one half weeks (10.2 mm.); outer surface, showing developing nerves. × 12. Drawn from His model.

The **optic nerve** is so inherently a derivative of the cerebral and optic vesicle, that its development is appropriately considered with that of the eye (page 1482); moreover, its morphological significance being so at variance with that of the other nerves, it may be omitted from further discussion in the series now being described.

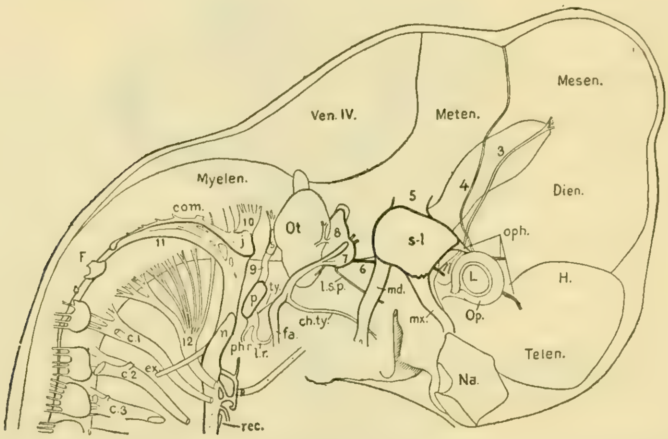
The **oculomotor nerve** being strictly a motor nerve has much in common in its mode of formation with the ventral root of a spinal nerve, with which it is homologous. The nerve originates as an outgrowth from a group of neuroblasts, which occupies the ventral zone about the middle of the mesencephalon. From these neurones, visible in the fourth week in the human embryo, the axones proceed as a converging group of fibres which, piercing the wall of the brain-tube close to the mid-line, appear on the ventral surface of the brain-stem as the fibres of the third nerve. Although by some regarded as possessing a transient rudimentary dorsal root that early entirely disappears, thus bringing the nerve of a cranial myomere into close correspondence with those of the spinal series, it is doubtful whether such structure is usually present, the suppression of the dorsal portion of the nerve being complete. Soon after its formation, the main trunk undergoes division into a smaller upper and a larger posterior limb, which foreshadow the superior and inferior divisions of the mature nerve.

The **trochlear nerve**, although springing from a central group of neuroblasts in close proximity with those giving rise to the third, is peculiar in the course of its axones. Instead of maintaining a ventral course, these proceed dorsally and become superficial on the upper (dorsal) aspect of the hind-brain, piercing the plate which later becomes the superior medul-

lary velum. As in the case of the third, so for the trochlear an abortive transient dorsal ganglion and root have been described (Martin). If present these must be regarded as exceptional and not constant features.

The **trigeminal nerve** is a mixed nerve and therefore takes its origin differently for its two roots. The motor one is developed from a series of neuroblasts, which lie at some distance from the mid-line within the wall of the neural tube, at a position corresponding to the junction of the dorsal and ventral zones of the mid-brain and metencephalon. The axones of these neuroblasts grow forward and converge to the surface of the later pons at a position close to where the ingrowing sensory fibres join the neural tube. The sensory fibres are the axones of neurones located within the Gasserian ganglion. The latter is derived as a ventrally directed outgrowth from the ectoblast of the roof of the hind-brain, with which it remains attached for a short time, but later becomes entirely separated. The neuroblasts acquire a bipolar form, one set of processes, the axones, growing centrally to establish secondary connections with the hind-brain as the large sensory root, while the others, the dendrites, extend peripherally into the substance of the fronto-nasal and maxillary processes to form the ophthalmic and maxillary nerves and into the mandibular process to form, in conjunction with the smaller motor root,

FIG. 1142.



Reconstruction of brain and cranial nerves of pig embryo; cranial nerves indicated by figures; c1-c3, cervical spinal nerves; in connection with seventh nerve., *l.s.p*, large superficial petrosal; *ch.ty.*, chorda tympani; *fa.*, facial; *j.*, *n.*, vagus ganglia of root and trunk; *com.*, commissural extension of ganglion of root; *F*, Froriep's hypoglossal ganglion. (*F. T. Lewis.*)

the mandibular division of the trigeminus from the ganglion ridge. Provision for the ciliary ganglion is made early by the migration of cells from the major ganglion along the developing ophthalmic division. Similar migrations along the other divisions give rise to the spheno-palatine, the otic and the submaxillary ganglia. The later histological characteristics of these cells, as well as their mode of origin, warrant the view that the ciliary ganglion, as well as the others connected with the trigeminus, belong to the sympathetic system. On entering the wall of the brain-tube, the bulk of the sensory trigeminal fibres assume a longitudinal course and early establish the tract of the spinal cord.

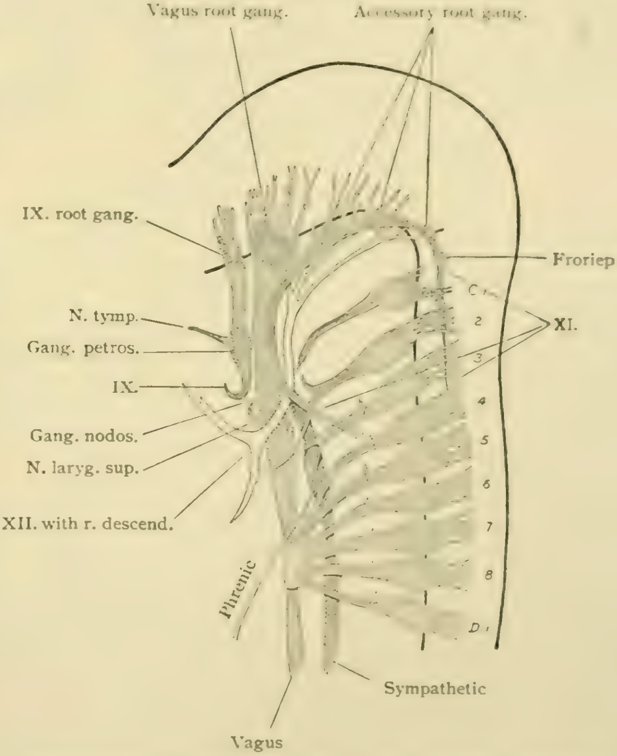
The **abducent nerve** developes, in a manner identical with the third and fourth, from a median group of cells occupying the ventral zone of the upper part of the hind-brain. In the human embryo of about four and a half weeks (Fig. 1141), the nerve appears at its superficial origin mesial to the Gasserian ganglion. The root-fibres early consolidate into a compact strand.

The **facial nerve** being a mixed one also arises from a double source, its motor fibres taking origin from efferent neuroblasts situated in the ventro-lateral wall of the metencephalon. In contrast to the direct ventral course of the axones of the mesial motor nerves, those of the facial pursue a path to the surface of the brain-stem even more indirect than that taken by the lateral motor fibres of the other mixed nerves. Proceeding as the axones of neuroblasts lying within the lateral part of the ventral zone of the wall of the hind-brain, they are directed dorsally, then grow forward, turn outward and, finally, ventrally to gain emergence from the brain. The sensory portion of the facial is topographically closely connected during its development with the auditory, the nuclei of the two nerves often being designated the facial-acoustic complex. The three components of this aggregation—the geniculate, the cochlear and the vestibular ganglia—are primarily derived from an ectoblastic cell-mass in the vicinity of the otic vesicle.

The neuroblasts of the facial constituent, the geniculate ganglion, send their centrally directed processes to the brain stem as the pars intermedia, whilst their peripherally growing dendrites contribute the sensory fibres, passing by way of the chorda tympani and the greater and lesser superficial petrosal nerves. The geniculate ganglion and the pars intermedia correspond, therefore, to a dorsal root.

The **auditory nerve**, although for a time closely related in position (Fig. 1103) with the facial (geniculate) ganglion, developes entirely independently and at no time has more than an incidental relation. The primary auditory nucleus is defined in human embryos by the beginning of the fourth week as an elongated ellipsoidal mass in contact with the anterior wall of the otic vesicle. According to Streeter[1], the nucleus very shortly exhibits a differentiation into a superior and an inferior part, from the latter of which soon appears a third portion. This third portion, the later ganglion spirale, early manifests a tendency to coil in consequence of its close relations with the ductus cochlearis. The major part of the primary acoustic complex, including the superior and most of the inferior part, becomes the vestibular ganglion, from the neuroblasts of which centrally directed axones pass to the young brain-stem as the vestibular nerve, while the dendrites become connected at certain places with the semicircular canals, the utricle and the saccule. The grouping of the vestibular rami seen in the adult is early foreshadowed in the developing nerve, since from the upper part of the vestibular ganglion grows out the superior division of the vestibular nerve which, supplies the utricle and the ampullæ of the superior and external semicircular canals (Fig. 1070). The lower part of the ganglion, in addition to furnishing the anlage for the cochlear nerve, gives off the inferior division of the vestibular nerve, by which the saccule and the posterior canal are supplied. During the subsequent growth of the structures, the neurones of the spiral ganglion send axones towards the brain which become the cochlear nerve, whilst their dendrites grow peripherally into the ductus cochlearis and are represented by the minute filaments extending from the cells of the spiral ganglion to the auditory cells of Corti's organ.

Fig. 1143.



Reconstruction of peripheral nerves of human embryo of five weeks (14 mm.) × 15. (*Streeter.*)

The **glosso-pharyngeal nerve** is a mixed nerve and has, therefore, a double origin. Its motor fibres arise from neuroblasts situated in the dorsal part of the ventral zone of the wall of the hind-brain just posterior to the otic vesicle. The sensory part of the nerve, along with that of the vagus, offers greater complexity, since it is developed, as shown by Streeter[2], from two sources. The ganglion of the root (g. superius or jugular ganglion) arises very early as a small mass of cells derived from the ganglion-crest of the hind-brain. It varies in size and soon ceases to grow, which behavior, in connection with the preponderating ingrowth of the motor fibres, accounts for the well-known inconstancy of the structure. The ganglion of the trunk (g. petrosum) arises, according to Streeter, not from the neural crest, but in relation with the ectoblast of the second visceral furrow. At first ununited with the smaller ganglion superius, the ganglion of the root subsequently becomes joined to it, the two nodes.

[1] Amer. Jour. of Anatomy, vol. vi., 1907.
[2] Amer. Jour. of Anatomy, vol. iv., 1904.

being later closely related, both as to position and fibres. An outgrowth of distally directed fibres establishes the main trunk of the nerve, while a forwardly growing strand represents the later tympanic branch.

The **vagus and spinal accessory nerves** are so inseparably related in their development that their origin must be regarded as proceeding from a common vagus complex. The latter comprises three elements: (*a*) a series of motor roots, which arise from the ventral zone of the hind-brain and extend from near the glosso-pharyngeal anlage in front as far as the third or fourth spinal segment below; (*b*) a partially subdivided, but at first continuous, ganglionic mass, which arises from the ganglion-crest of the hind-brain and represents the root-ganglia; (*c*) a secondary ventral cell-mass, the primitive ganglion of the trunk, which, as in the case of the glosso-pharyngeal nerve, is developed in close relation with the ectoblast of the posterior branchial furrows. Whilst the motor rootlets persist and become the efferent root-fibres of the later vagus and accessory nerves, the dorsal or crest-ganglia soon exhibit differences in their growth, the one situated farthest forward outstripping the others and becoming the vagal ganglion of the root, and the remaining ones becoming the accessory root-ganglia. These latter constitute a chain which below meets with the spinal dorsal ganglia. Primarily, therefore, the entire length of the vagus complex is occupied by a series of mixed nerve strands possessing both motor and sensory elements. The head-end of the series later becomes predominatingly sensory, while in the tail-end of the same the motor character prevails. The ventral vagus nucleus is attached secondarily to the dorsal nucleus by centrally growing fibres, while from its distal end extend the dendritic processes which constitute the trunk of the vagus and its branches. In consequence of the intergrowth of these afferent and efferent fibres, the definite tenth nerve in the usual sense, with its two ganglia, becomes established. Although for a short period the accessory part of the complex is provided with both motor and sensory parts, the latter are subsequently overpowered by the efferent fibres, so that the presence of the rudimentary ganglionic elements within the accessorius can be demonstrated only by microscopic examination (Streeter). From the preceding facts it is evident that the estimate of the eleventh nerve as an integral part of the vagus is well founded.

The **hypoglossal nerve** appears in the human embryo, towards the close of the third week, as several strands which grow from the ventral zone of the wall of the hind-brain and are in series with the ventral root-fibres of the upper cervical spinal nerves. Soon the separate rootlets converge and consolidate into a common trunk, from which, by the end of the fifth week, the chief branches of distribution arise. The production of the wide-meshed net-work which distinguishes the communications between the upper cervical and hypoglossal nerves results from the separation of fibres which are at first closely adjacent, the subsequent migration of the growing tongue-muscles drawing the hypoglossal fibres away from the spinal nerves, except at such points where they have become enclosed in a common sheath. There is good reason for regarding the hypoglossal nerve as representing the ventral roots of trunk-nerves, which have been cephalicly displaced and drawn within the cranium. Moreover, the observations of Froriep and others upon adult mammals and of His upon the human embryo have shown the presence of a rudimentary dorsal ganglion and abortive dorsal root-fibres. The occasional presence of a rudimentary ganglionic mass, known as Froriep's ganglion, attached to the fibres of the adult hypoglossal nerve in man is to be interpreted as the persistent dorsal element which ordinarily disappears.

From the preceding sketch it is evident that in no instance, as observed in the usual adult condition in man, is there complete correspondence between the members of the cephalic series and those of the trunk. The group of purely sensory nerves—the olfactory, optic and auditory—includes one, the optic, which is so exceptional in its fundamental relations as to lie without the pale of peripheral nerves in their strict sense. The remaining two sensory nerves are held to be primarily the equivalents of constituents of a peculiar system of sensory organs, best developed in fishes, known as the organs of the lateral line. The third, fourth, sixth and twelfth, the ventral motor nerves, are undoubtedly associated with head-somites, although the exact number and nerve relations of such mesoblastic segments are uncertain; in fundamental significance, therefore, these nerves agree with those of the trunk-series, although modified by the suppression of their dorsal or sensory constituents. The mixed nerves—the fifth, seventh, ninth and tenth (the eleventh being reckoned as part of the vagus)—are unrepresented in the spinal series and belong to the branchiomeres represented by the visceral arches. Of these nerves, the trigeminus most nearly accords in constitution with a typical spinal nerve, since, with the exception of ventral motor constituents which are wanting, it possesses as does the typical spinal nerve, both somatic (general cutaneous) sensory and visceral sensory fibres. A further resemblance is found in the character of the gray matter constituting the reception-nucleus for the sensory fibres of the trigeminus, since this column is composed of substantia gelatinosa continuous with the Rolandic substance capping the posterior cornu of the cord. A similar, although less intimate, arrangement is seen in the column of gray matter accompanying the descending root (funiculus solitarius) of the facial, glosso-pharyngeal and vagus nerves.

THE ORGANS OF SENSE.

The cells directly receiving the stimuli producing the sensory impressions of touch, smell, taste, sight and hearing are all derivations of the ectoblast—the great primary sensory layer from which the essential parts of the organs of special sense are differentiations. The olfactory cells—nervous elements that correspond to ganglion cells—retain their primary relation, since they remain embedded within the invaginated peripheral epithelium lining the nasal fossæ, sending their dendrites towards the free surface and their axones into the brain. Usually, however, the nerve cells connected with the special sense organs abandon their superficial position and lie at some distance from the periphery, receiving the stimuli not directly, but from the epithelial receptors by way of their dendrites. In the case of the most highly specialized sense organs, the eye and the ear, the percipient cells lie enclosed within capsules of mesoblastic origin, the stimuli reaching them by way of an elaborate path of conduction.

THE SKIN.

Since the extensive integumentary sheet that clothes the exterior of the entire body not only serves as a protective investment, an efficient regulator of body temperature and an important excretory structure, but also contains the special end-organs and the peripheral terminations of the sensory nerves that receive and convey the stimuli producing tactile impressions, the skin may be appropriately considered along with the other sense-organs of which it may be regarded as the primary and least specialized. On the other hand, the correspondence of its structure with that of the mucous membranes, with which it is directly continuous at the orifices on the exterior of the body, emphasizes the close relation of the skin to the alimentary and other mucous tracts.

This general investment, the **tegmentum commune**, includes the *skin proper*, with the specialized tactile corpuscles, and its *appendages*—the *hairs*, the *nails* and the *cutaneous glands*. Its average superficial area is approximately one and a half square meters.

The **skin** (**cutis**), using the term in a more restricted sense as applied to the covering proper without its appendages, everywhere consists of two distinct portions—a superficial *epithelial* and a deeper *connective tissue stratum*. The former, the *epidermis*, is devoid of blood-vessels, the capillary loops of which never reach farther than the subjacent *corium*, as the outermost layer of the connective tissue stratum is called.

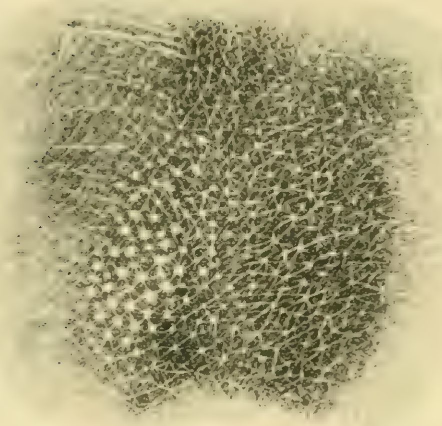
The **thickness** of the skin, from .5–4 mm., varies greatly in different parts of the body, being least on the eyelids, penis and nymphæ, and greatest on the palms of the hands and soles of the feet and on the shoulders and back of the neck. In general, with the exception of the hands and feet, the skin is thicker on the extensor and dorsal surfaces than on the opposite aspects of the body. Of the entire thickness, the proportion contributed by the epidermis is variable, but in most localities it is about .1 mm. Where exposed to unusual pressure, as on the palms of laborers or on habitually unshod soles, the epidermis may attain a thickness of 4 mm.

As seen during life, the **color** of the skin results from the blending of the inherent tint of the tissues with that of the blood within the superficial vessels. When the latter are empty, as after death, the skin assumes the characteristic pallor and ashen hue. Where the capillaries are numerous and the overlying strata thin, the skin exhibits the pronounced rosy color of the lips, cheeks, ears and hands. Where, on the contrary, the contents of fewer vessels shimmer through the epidermis, the paler tint of the limbs and trunk is produced.

In certain localities—especially over the mammary areolæ after pregnancy, the axillæ, the external genital organs and around the anus—the skin presents a more or less pronounced brownish color owing to the unusual quantity of pigment within the

epidermis. The amount of skin-pigment not only differs permanently among races (white, yellow and black) and individuals (blond and brunette), but also varies in the same person with age and exposure, as contrasted by the rosy tint of the infant and the bronzed tan of the weather beaten mariner.

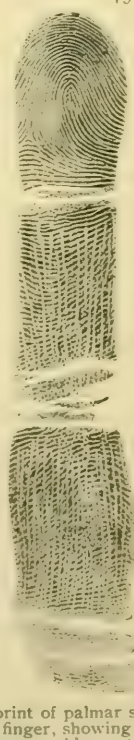
Fig. 1144.



Imprint of dorsal surface of left hand near ulnar border; radiating lines are produced by creases connecting points at which hairs emerge.

Unless bound down to the underlying tissues, as it is over the scalp, external ear, palms and soles, the skin is freely movable. Its **physical properties** include considerable extensibility and marked elasticity. By virtue of the latter the temporary displacement and stretching produced by movements of the joints and muscles is overcome and the smoothness of the skin, so conspicuous in early life, is maintained. With advancing age the elasticity becomes impaired and folds are no longer effaced, resulting in the permanent wrinkles seen in the skin of old people. Certain folds and furrows, however, are not only permanent and ineffaceable, appearing in the fœtus, but are fairly constant in position and form. One group, produced by flexion of the joints, includes the conspicuous creases on the flexor surface of the wrist, palm and fingers, and the similar markings on the soles of the feet. The other group, more extensive but less striking, includes the fine grooves that connect the points of emergence of the hairs and cover the trunk and extensor surface of the limbs with a delicate tracery (Fig. 1144).

Fig. 1145.



Imprint of palmar surface of left middle finger, showing arrangement of cutaneous ridges; transverse interruptions are produced by flexion creases over joints.

The **surface modelling** of the skin covering the palms, soles and flexor aspects of the digits is due to the disposition of numerous minute ridges (**cristae cutis**) and furrows (**sulci cutis**). The *cutaneous ridges*, about .2 mm. in width, correspond to double rows of papillæ which they cover, the sweat glands opening along the summit of the crests. The patterns formed by the cutaneous ridges (Fig. 1145) remain throughout life unchanged and are so distinctive for each individual that they afford a reliable and practical means of identification. In addition to the various longitudinal, transverse and oblique ranges of ridges that cover the greater part of the hand, groups of concentrically arranged ridges occupy the volar surface over the distal phalanges, the pads between the metacarpo-phalangeal joints and the middle of the hypothenar eminence. These highly characteristic areas, the so-called **tactile pads** (**toruli tactiles**) are most strikingly developed over the bulbs of the fingers, where the ridges are often disposed in whorls rather than in regular ovals. The markings of corresponding areas of the two hands are symmetrical and sometimes identical.

Structure.—The two parts of which the skin is everywhere composed—the epidermis and the connective tissue stratum—are derivatives of the ectoblast and of the mesoblast respectively. The connective tissue portion includes two layers,

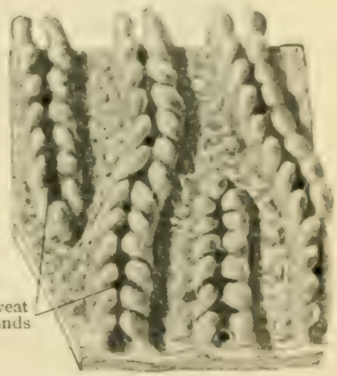
the *corium* and the *tela subcutanea*, which, however, are so blended with each other as to be without sharp demarcation.

The **corium** or **derma,** the more superficial and compact of the connective tissue strata, lies immediately beneath the epidermis from which it is always well defined. With the exception of within a few localities, as over the forehead, external ear and perineal raphe, the outer surface of the corium is not even but beset with elevations, ridges, or papillæ, which produce corresponding modelling of the opposed under surface of the overlying epidermis. The pattern resulting from these elevations varies in different regions, being a net-work with elongated meshes over the back and front of the trunk, with more regularly polygonal fields over the extremi-

FIG. 1146.

Portion of corium from palmar surface of hand after removal of epidermis; each range includes a double row of papillæ, which underlie the superficial cutaneous ridges and enclose openings of sweat glands; latter appear as dark points along ranges of papillæ. × 5.

FIG. 1147.



Small portion of preceding specimen, showing papillæ under higher magnification; orifices of torn sweat glands are seen between papillæ. × 24.

ties and with small irregular meshes on the face (Blaschko). The best developed papillæ are on the flexor surfaces of the hands and feet, where they attain a height of .2 mm. or more and are disposed in the closely set double rows that underlie the cutaneous ridges on the palms and soles above noted. The papillæ afford favorable positions for the lodgement of the terminal capillary loops and the special organs of touch and are accordingly grouped as vascular and tactile.

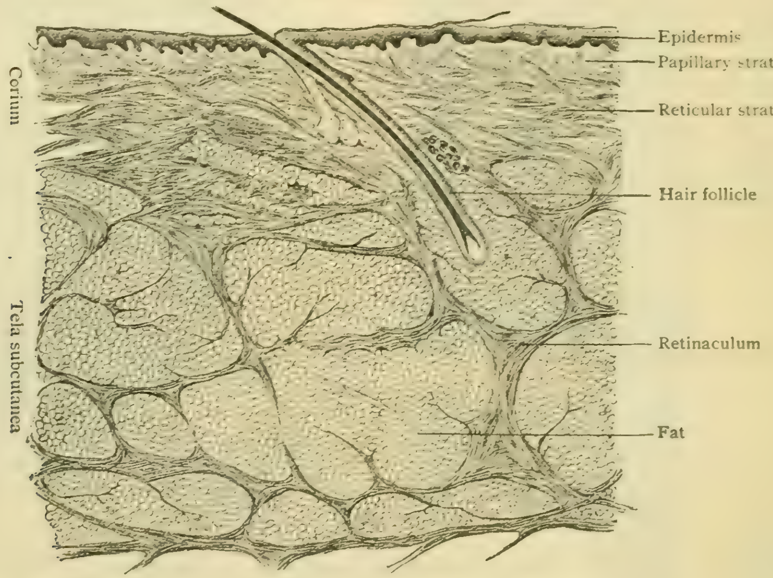
In recognition of the elevations, which in vertical sections of the skin appear as isolated projections, the corium is subdivided into an outer *papillary stratum* (**corpus papillare**), containing the papillæ, and a deeper *reticular stratum* (**tunica propria**), composed of the closely interlacing bundles of fibrous and elastic tissue that are continued into the more robust and loosely arranged trabeculæ of the tela subcutanea. These two strata of the corium, however, are so blended that they pass insensibly and without definite boundary into each other. Although composed of the same histological factors—bundles of fibrous tissue, elastic fibres and connective tissue cells—the disposition of these constituents is much more compact in the dense reticular stratum than in the papillary layer, in which the connective tissue bundles are less closely interwoven. While the general course of the fibrous bundles within the corium is parallel or oblique to the surface, some strands, continued upward from the underlying subcutaneous sheet, are vertical and traverse the stratum reticulare either to bend over and join the horizontal bundles or to break up and disappear within the papillary stratum. The elastic tissue,

which constitutes a considerable part of the corium, occurs as fibres and net-works, which within the reticular stratum form robust tracts corresponding in their disposition with the general arrangement of the fibrous bundles. Towards the surface of the corium, the elastic fibres become finer and more branched and beneath the epidermis anastomose to form the delicate but close *subepithelial elastic net-work* that is present over the entire surface of the body with the exception, possibly, of the eyelids (Behrens).

The **tela subcutanea**, the deeper layer of the connective tissue portion of the skin, varies in its thickness, and in the density and arrangement of its component bundles of fibro-elastic tissue, with the amount of fat and the number of hair-follicles and glands lodged within its meshes.

The latter are irregularly round and enclosed by tracts of fibrous tissue, some of which, known as the *retinacula cutis*, are prolonged from the corium to the deepest parts of the subcutaneous stratum. Here they often blend into a thin but definite sheet, the *fascia subcutanea*, which forms the innermost boundary of the skin and is

FIG. 1148.



Section of skin, showing its chief layers—epidermis, corium and tela subcutanea. × 17.

connected with the subjacent structures by strands of areolar tissue. Where such loose connection is wanting, as on the scalp, face, abdomen (linea alba), palms and soles, the skin is intimately bound to the underlying muscles or fasciæ and lacks the independent mobility that it elsewhere enjoys. The integument covering the eyelids and penis is peculiar in retaining to a conspicuous degree its mobility although devoid of fat. Where the latter is present in large quantity, the term *panniculus adiposus* is often applied to the tela subcutanea.

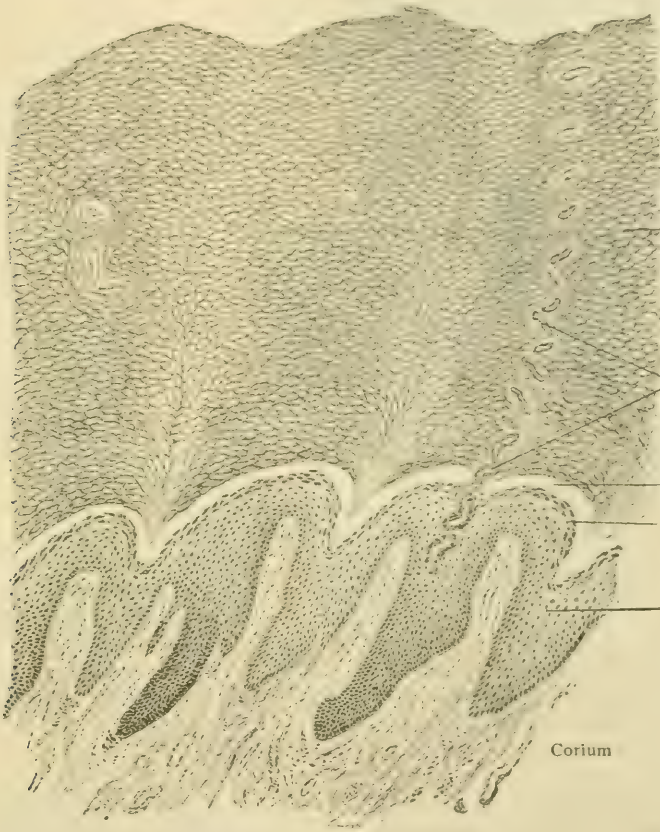
In places in which the skin glides over unyielding structures, the interfascicular lymph-spaces of the tela subcutanea may undergo enlargement and fusion, resulting in the production of the subcutaneous mucous bursæ. These are found in many localities, among the most constant bursæ being those over the olecranon, the patella and the metatarso-phalangeal joints of the little and the great toe. The bursæ in the latter situation, when abnormally enlarged, are familiar as bunions.

In addition to the strands of *involuntary muscle* associated with the hairs as the arrectores pilorum, unstriped muscular tissue is incorporated with the skin in the mammary areolæ and over the scrotum and penis (tunica dartos). The facial muscles having largely cutaneous insertions, the skin covering the face is invaded by tracts of striated muscular tissue that penetrate as far as the corium.

The **epidermis** or **cuticle,** the outer portion of the skin, consists entirely of epithelium and, being partly horny, affords protection to the underlying corium with its vessels and nerves. The thickness of this layer varies in different parts of the body. Usually from .08–.10 mm., it is greatest on the flexor surfaces of the hands and feet, where it reaches from .5–.9 mm. and from 1.1–1.3 mm. respectively (Drosdoff).

The cuticle consists of two chief layers, the deeper *stratum germinativum*, containing the more active elements, and the *stratum corneum*, the cells of which undergo cornification. Between these layers lies a third, the *stratum intermedium*, that is

FIG. 1149.



Portion of section of skin from sole of foot, showing layers of epidermis. × 70.

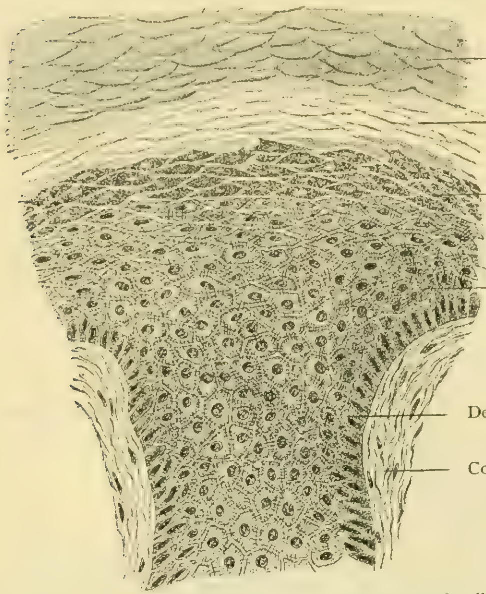
ordinarily represented by only a single row of cells to which the name, *stratum granulosum*, is usually applied. This layer marks the level at which the conversion of the epithelial elements into horny plates begins and also that at which the separation effected by blistering usually occurs.

On the palms and soles, where the epidermis attains not only great thickness but also higher differentiation, four distinct layers may be recognized in vertical sections of the cuticle. From the corium outward, these are: (1) the *stratum germinativum*, (2) the *stratum granulosum*, (3) the *stratum lucidum* and (4) the *stratum corneum*. The first two represent the portion of the epidermis endowed with the greatest vitality and powers of repair and the last two the horny and harder part.

The **stratum germinativum,** or *stratum Malpighi*, rests upon the outer surface of the corium, by the papillæ of which it is impressed and, hence, when viewed from beneath after being separated, commonly presents a more or less evident net-work of ridges and enclosed pits, the elevations corresponding to the

interpapillary furrows and the depressions to the papillæ. In recognition of this reticulation the name, *rete Malpighi*, is sometimes applied to the deepest layer of the epidermis. As in other epithelia of the stratified squamous type, the deepest cells are columnar and lie with their long axes perpendicular to the supporting connective tissue. The basal ends of the columnar cells are often slightly serrated and fit into corresponding indentations on the corium. Their outer ends are rounded and received between the superimposed cells. Succeeding the single row of columnar elements, the cells of the stratum germinativum assume a pronounced polygonal form, but become somewhat flatter as they approach the stratum granulosum. The number of layers included in the germinal stratum is not only uncertain, but varies with the relation to the papillæ, being greater between than over these projections. The finely granular cytoplasm of the cells of the stratum germinativum contains delicate but distinct *fibrillæ*, which, longitudinally disposed in the deep columnar cells, in the polygonal elements (Fig. 1151), radiate from the nucleus towards the periphery (Kromayer). The fibrillæ are not confined to the cells, but extend beyond and pass across the intercellular lymph-clefts as delicate protoplasmic bridges that connect the units of the various layers of the stratum and confer upon them the characteristics of the so-called "prickle cells."

FIG. 1150.



Portion of preceding preparation, showing in more detail layers of epidermis; only deeper part of stratum corneum is represented. × 280.

The **stratum granulosum** is exceptionally well marked on the palms and soles and in these localities includes from two to four rows of polygonal cells, somewhat horizontally compressed, that stand out conspicuously in stained sections by reason of the intensely colored particles within their cytoplasm. The nature of the peculiar substance, deposited within the body of the cells as particles of irregular form and size, is still uncertain. To it Ranvier gave the name of *eleidin* and Waldeyer that of *keratohyalin*. Since the nuclei of the cells in which the deposits occur always exhibit evidences of degeneration, it is probable that keratohyalin is in some way derived from disintegration of the nucleus (Mertsching) and represents a transition stage in the process ending in cornification of the succeeding layers of the cuticle (Brunn).

FIG. 1151.

Portion of horizontal section of skin, showing intracellular fibrillæ within cells of stratum germinativum. × 800.

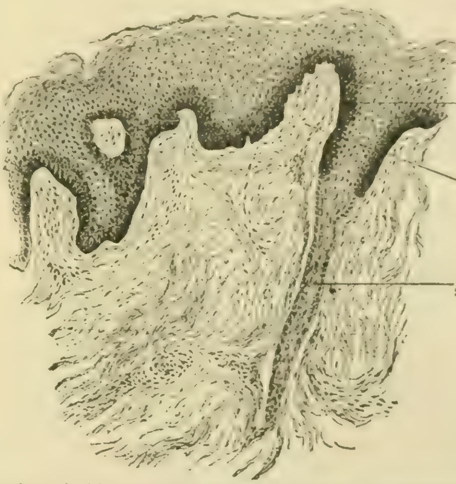
The **stratum lucidum**, usually wanting in other localities, in the palm and sole appears as a thin, almost homogeneous layer, separating the corneous from the

granular layer. With the latter it constitutes the stratum intermedium. As indicated by its name, the stratum lucidum appears clear and without distinct cell boundaries, although suggestions of these, as well as of the nuclei of the component elements, are usually distinguishable. The cells of the stratum lucidum are but little cornified and differ, therefore, from those of the overlying layers; moreover, the eleidin within the cells of the stratum lucidum probably is in a fluid condition.

The **stratum corneum** includes the remainder of the epidermis and consists of many layers of horny epithelial cells that form the exterior of the skin. Where no stratum lucidum exists, as is usually the case, the corneous layer rests upon the stratum granulosum, from which its horny elements are being continually recruited. During their migration towards the free surface, the cells lose their vitality and become more flattened until the most superficial ones are converted into the dead horny scales that are being constantly displaced by abrasion.

The **pigmentation** of the skin, which even in white races is conspicuous in certain regions (page 1381), depends upon the presence of colored particles chiefly within the epidermis, although, when the dark hue is pronounced, a few small branched pigmental connective tissue cells may appear within the subjacent corium. The distribution of the pigment particles varies with the intensity of color, in skins of lighter tints being principally, and sometimes entirely, limited to the columnar cells next the corium. With increasing color the pigment particles invade the neighboring layers of epithelium until, in the dark skin of the negro, they are found within the cells of the stratum corneum but always in diminishing numbers towards the free surface. Even when the cells are dark and densely packed, the colored particles never encroach upon the nuclei, which, therefore, appear as conspicuous pigment free areas.

FIG. 1152.



Section of skin, surrounding anus, showing pigmentation of deeper layer of epidermis. × 50.

The source of the pigment within the epidermis is uncertain, by some being found in an assumed transference of the colored particles from the corium, by means of wandering cells or of the processes of pigmented connective tissue cells that penetrate the cuticle, and by others ascribed to an independent origin *in situ* within the epithelial elements. While it may be accepted as established that at times the connective tissue cells are capable of modifying pigmentation (Karg), it is equally certain that the earliest, and probably also later, intracellular pigmentation of the epidermis appears without the assistance of the connective tissue or migratory cells.

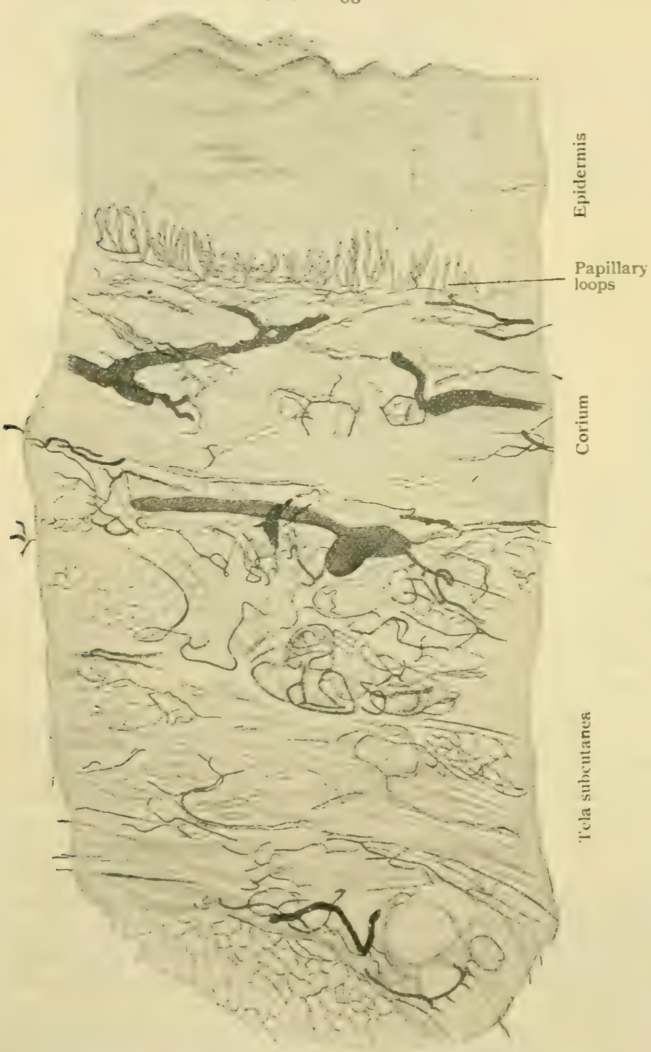
The **blood-vessels** of the skin are confined to the connective tissue portion and never enter the cuticle. The *arteries* are derived either from the trunks of the subjacent layer as special cutaneous branches destined for the integument, or indirectly from muscular vessels. When the blood supply is generous, as in the palms and soles and other regions subjected to unusual pressure or exposure, the arteries ascend through the subdermal layer to the deeper surface of the corium where, having subdivided, they anastomose to form the *subcutaneous plexus* (**rete arteriosum cutaneum**). From the latter some twigs sink into the subdermal layer and contribute the capillary net-works that supply the adipose tissue and the sebaceous glands.

Other twigs, more or less numerous, pass outward through the deeper part of the corium and within the more superficial stratum unite into a second, *subpapillary plexus* (**rete arteriosum subpapillare**), that extends parallel to the free surface and

beneath the bases of the papillæ. The latter are supplied by the terminal twigs which ascend vertically from the subpapillary net-work and break up into capillary loops that occupy the papillæ and lie close beneath the epidermis (Fig. 1153). With the exception of the loops entering the hair-papillæ, the capillaries enclosing the hair-follicles arise from the subpapillary plexus.

The arrangement of the cutaneous *veins*, more complex than that of the arteries, includes four plexuses (**retia venosum**) lying at different levels within the corium and extending parallel to the surfaces. The first and most superficial one is formed by the union of the radicles returning the blood from the papillæ. The component veins lie below and parallel to the rows of papillæ and immediately beneath the bases of the latter. At a slightly lower level, in the deeper part of the stratum papillare, the venous channels proceeding from the subpapillary net-work join to form a second plexus with polygonal meshes. A third occurs about the middle of the corium, while the fourth shares the position of the subcutaneous arterial plexus at the junction of the corium and subdermal strata. The deepest plexus receives many of the radicles returning the blood from the fat and the sweat glands, the remainder being tributary to the veins accompanying the larger arteries as they traverse the tela subcutanea.

FIG. 1153.



Section of injected skin, showing general arrangement of blood-vessels. × 40.

The *lymphatics* of the skin are well represented by a close *superficial plexus* within the papillary stratum of the corium into which the terminal lymph-radicles of the papillæ empty. The relation of these channels to the interfascicular connective tissue spaces is one only of indirect communication, since the lymphatics are provided with fairly complete endothelial walls. It is probable that the lymph-paths within the papillæ are closely related to the intercellular clefts of the epidermis, according to Unna, indeed, direct communications existing. Migratory leucocytes often find their way into the cuticle where they then appear as the irregularly stellate *cells of Langerhans* seen between the epithelial elements. A wide-meshed *deep plexus* of lymphatics is formed within the subdermal layer, from which the larger lymph-trunks pass along with the subcutaneous blood-vessels.

The numerous **nerves** within the highly sensitive integument are chiefly the peripheral processess of sensory neurones which terminate in free arborizations between the ephithelial elements of the cuticle, or in relation with special endings located, for the most part, within the corium or subdermal connective tissue. Some sympathetic fibres, however, are present to supply the tracts of involuntary muscle that occur within the walls of the blood-vessels or in association with the hairs and the sweat glands.

On entering the skin the medullated nerves traverse the subdermal layer, to which they give off twigs in their ascent, and, passing into the corium, within the papillary stratum divide into a number of branches. Those destined for the epidermis beneath the latter break up into many fibres which, losing their medullary substance, enter the cuticle and end in arborizations that ramify between the epithelial cells as far as the outer limits of the stratum germinativum. The ultimate endings of the fibrillæ, whether tapering or slightly knobbed, always occupy the intercellular channels and are never directly connected with the substance of the epithelial elements. According to Merkel, special *tactile cells*, (Fig. 867) occur in the human epidermis, particularly over the abdomen and the thighs. These cells, spherical or pyriform in shape and composed of clear cytoplasm, occupy the deeper layers of the cuticle and, on the side directed towards the corium, are in contact with the end-plate or meniscus of the nerve.

The nerve-fibres particularly concerned with the sense of touch terminate within the connective tissue portion of the skin, either within the corium in *special end organs* —the tactile bodies of Meissner, the end-bulbs of Krause, the genital corpuscles and the end-organs of Ruffini, or within the subdermal layer in the Vater-Pacinian corpuscles, or their modifications, the Golgi-Mazzoni corpuscles. The structure of these special end-organs is elsewhere described (pages 1018, 1019), their chief locations being here noted.

Meissner's corpuscles (Fig. 872) are especially numerous in the tactile cushions on the flexor surface of the hands and feet. While much more plentiful in all the tactile pads than in the intervening areas, the touch corpuscles are most abundant in those on the volar surface of the distal phalanges, where they approximate twenty to the square millimeter (Meissner). Their favorite situation is the apex of the papillæ, where they appear as elongated elliptical bodies, sometimes in pairs, whose outer pole lies immediately below the epidermis. These corpuscles are additionally, although sparingly, distributed on the dorsum of the hand, the flexor surface of the forearm, the lips, the eyelids, the nipple and the external genital organs.

The **Vater-Pacinian corpuscles** (Fig. 874) are well represented in the hands and feet and usually occupy the subdermal tissue, although sometimes found within the corium. Their distribution corresponds closely to that of Meissner's corpuscles, they being most numerous beneath the tactile cushions in the order above described.

The **Golgi-Mazzoni corpuscles** are modifications of the Pacinian bodies and, like the latter, are found within the subdermal tissue.

The **end-bulbs of Krause** (Fig. 869) occur within the corium, either slightly below or within the papillæ, on the lips and external genital organs, as well as probably in other regions.

The **genital corpuscles** (Fig. 870) lie within the corium of the modified skin covering the glans penis and the prepuce and the clitoris and surrounding parts of the nymphæ.

The **end-organs of Ruffini** resemble the sensory terminations in tendons (page 1017) and lie within the deeper parts of the corium, often associated with the Pacinian bodies.

The mode of ending of the nerves supplying the hairs and sweat glands will be described in connection with those structures (pages 1394, 1400).

THE HAIRS.

The appendages of the skin—the hairs, nails and cutaneous glands—are all specializations of the epidermis and are, therefore, exclusively of ectoblastic origin.

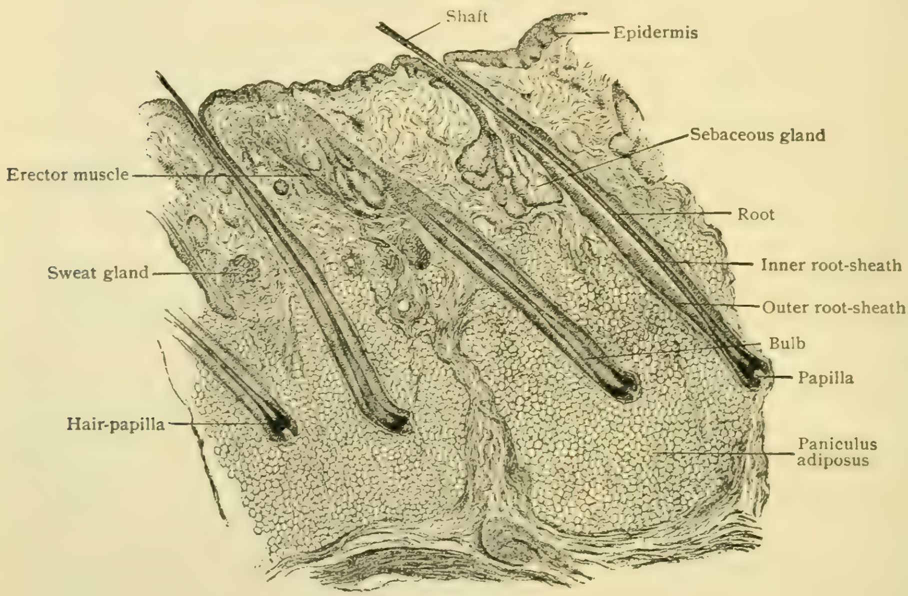
The **hairs** (pili) are present over almost the entire body, the few localities in which they are absent being the flexor surface of the hands and feet, the extensor aspect of the terminal segment of the fingers and toes, the inner surface of the

prepuce and of the nymphæ and the glans penis and clitoridis. With the exception of those regions in which the growth is sufficiently long to constitute a complete covering—the scalp, bearded parts of the face in the male, axillæ and mons pubis—the hairs are for the most part short and scattered, although subject to great individual variation and sometimes to remarkable redundance.

The hairs in various locations are known by special names; those of the scalp being *capilli;* of the eyebrows, *supercilia;* of the eyelashes, *cilia;* of the nostrils, *vibrissæ;* of the external ear, *tragi;* of the beard, *barba;* of the axillæ, *hirci;* of the pubes, *pubes;* while the fine downy hairs that cover other parts of the body are designated *lanugo.*

The closest set hairs are on the scalp, where, according to Brunn, on the vertex they number from 300–320, and in the occipital and frontal regions from 200–240 per square centimeter. On the chin 44 were counted, on the mons pubis 30–35,

FIG. 1154.



Section of scalp, showing longitudinally cut hair-follicles. × 14.

on the extensor surface of the forearm 24 and on the back of the hand 18 for like areas. Even where their distribution is seemingly uniform, close inspection shows the hairs to be arranged in groups of from two to five.

The **length** of the hairs includes the extremes presented by the lanugo, only a few millimeters long, on the one hand, and by the scalp-growth, sometimes measuring 150 cm. (59 in.) or more, on the other. Their **thickness**, likewise, shows much variation, not only in different races, individuals and regions, but also in the same person and part of the body, as on the scalp where fine and coarse hairs may lie side by side. The thickest scalp-hairs have a diameter of .162 mm. and the finest one of .011 mm., with all intermediate sizes. The hairs of the beard vary from .101–.203 mm. and those on the pubes from .054–.135mm. (Falck). In a general way hairs of light color are finer than dark ones, the respective diameters of blond, brown and black hairs being .047, .054 and .067 mm. (Wilson). On attaining their full growth without mutilation, hairs do not possess a uniform thickness throughout their length, since they diminish not only towards the tip, where the shaft ends in a point, but also towards the root. This feature is most evident in short hairs, as in those of the eyebrows.

The **color** of the hair, which varies from the lightest straw to raven black, is closely associated with racial and individual characteristics, being usually, but by no

means always, in harmony with the degree of general pigmentation. The latter is commonly uniform throughout the length of the hair, but in rare cases it may be so variable that the shaft presents a succession of alternating light and dark zones (Brunn). The straight and curly varieties of hair depend chiefly upon differences in the curvature of the follicle [1] and the form of the hair. In the case of straight hairs the follicle is unbent and the shaft is cylindrical, and therefore circular in cross-section ; hairs that are wavy or curly spring from follicles more or less bent and are flattened or grooved, with corresponding oval, reniform, irregularly triangular or indented outlines when transversely cut.

Arrangement of the Hairs.—Since the buried part of the hair, the *root*, is never vertical but always oblique to the surface of the skin, it follows that the free part, the *shaft*, is also inclined. The direction in which the hairs point, however, is by no means the same all over the body, but varies in different regions although constant for any given area. This disposition depends upon the peculiar placing of the hair-roots which in certain localities incline towards one another along definite lines, an arrangement that results in setting the shafts in opposite directions. As these root-lines are not straight but spiral, on emerging from the skin the hairs diverge in **whorls** (**vortices pilorum**), the position and number of which are fairly definite.

Such centres include : (1) the conspicuous *vertex whorl* on the head, usually single but sometimes double ; (2) the *facial whorls* surrounding the openings of the eyelids ; (3) the *auricular whorls* at the external auditory meatus ; (4) the *axillary whorls* in the armpits ; and (5) the *inguinal whorls*, just below the groin ; additional (6) but less constant *lateral whorls* may be located, one on each side, about midway between the axilla and the iliac crest and somewhat beyond the outer border of the rectus muscle.

These whorls, all paired except the first, apportion the entire surface of the body into certain districts, each covered by the hairs proceeding from the corresponding vortex. The whorl-districts, moreover, are irregularly subdivided into secondary areas by lines, the **hair-ranges** (**flumina pilorum**), along which the hairs diverge in opposite directions. Additional lines, the **converging hair-ranges**, mark the meeting of tracts pointing in different directions and in places also assume a spiral course. In consequence of these peculiarities the body is covered with an elaborate and intricate **hair-pattern**, that is most evident on the fœtus towards the close of gestation ; later in life the details of the pattern are uncertain owing to its partial effacement by the constant rubbing of clothing.

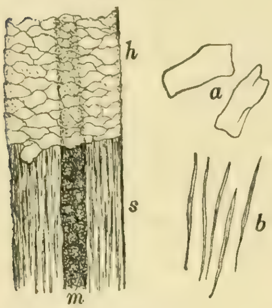
Structure.—Each hair consists of two parts, the *shaft*, which projects beyond the surface, and the *root*, which lies embedded obliquely within the skin, the deepest part of the root expanding into a club-shaped thickening known as the *bulb*. The root is covered with a double investment of epithelial cells, the inner and outer *root-sheaths*, which, in turn, are surrounded by a connective tissue envelope, the *theca*. The entire sac-like structure, consisting of the hair-root and its coverings, constitutes the **hair-follicle** (**folliculus pili**). At the bottom of the latter, immediately beneath the bulb, the wall of the follicle is pushed upward to give place to a projection of connective tissue, the *hair-papilla*, which carries the capillary loops into close relation with the cells most active in the production of the hair. Save in the case of the finest hairs (lanugo), which are limited to the corium, the hair-follicles traverse the latter and end at varying levels within the fat-laden subdermal layer (panniculus adiposus). In a general way the follicle may be regarded as a narrow tubular invagination of the epidermis, at the bottom of which the hair is implanted and from the entrance of which the shaft projects. The most contracted part of the follicle, the *neck*, lies at the deeper end of the relatively wide funnel-shaped entrance to the sac. Closely associated with the hair-follicle, which they often surround, are the *sebaceous glands* that pour their oily secretion at the upper third of the follicle into the space between the shaft and the wall of the sac.

The Hair-Shaft.—In many thick hairs, but by no means in all, three parts can be distinguished—the *cuticle*, the *cortex* and the *medulla*. The latter, however, is usually wanting in hairs of ordinary diameter, being often also absent in those of large size.

[1] Frederic : Zeitschr. f. Morph. u. Anthropol., Bd. ix., 1906.

The **cuticle** of the hair appears as a transparent outermost layer marked by a net-work of fine sinuous lines, the irregular meshes of which have their longest diameter placed obliquely transverse. These lines correspond to the free borders of extremely thin glassy cuticle-plates that overlie the hair as tiles on a roof, the imbrication involving from four to six layers. Seen in profile (Fig. 1155), the contour of the hair-shaft, therefore, is not smooth but serrated, the minute teeth formed by the free margins of the scales being directed towards the tip of the hair. After isolation by suitable reagents, the cuticular elements appear as transparent structureless cells, quadrilateral in outline and curved to conform to the hair-shaft which they cover.

FIG. 1155.

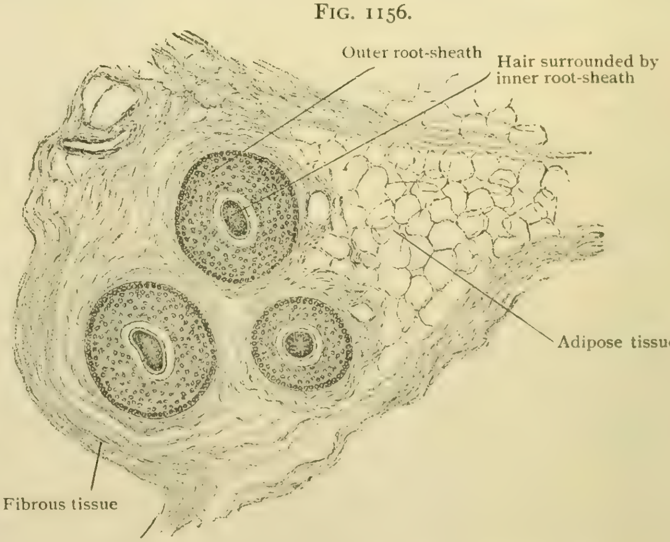


Portion of shaft of hair; *h*, shaft covered with cuticle; *s*, cuticle removed to expose cortical substance; *m*, medulla × 125. *a*, *b*, isolated cells of cuticle and of cortical substance respectively. × 240.

The **cortical substance**, often indeed constituting practically the entire shaft, consists of elongated fusiform cells so compactly arranged that the individual elements are only distinguishable after the action of disassociating reagents. In addition to the remains of the shrunken nuclei the *hair-spindles*, as these modified epithelial cells are called, possess fibrillæ that pass between adjacent cells similar to the intercellular bridges in the epidermis. A variable amount of *pigment*, present either as a diffuse tint of the spindles, or as granules within or between the same, is a constant constituent of the cortical substance. In blond hair the color is chiefly diffuse, the pigment granules being often entirely wanting; in hair of darker shades, the granules predominate and increase in intensity of color as well as in quantity. As the hair grows outward from the bulb, it loses much of its moisture, and in consequence later contains minute air-vesicles that replace the fluid previously occupying the clefts between the hair-spindles. Even when conspicuous, the medulla does not extend the entire length of the hair, often being interrupted and always disappearing before reaching the tip.

The **medulla**, when well represented, is seen as an axial stripe, somewhat uneven in outline, that varies with illumination, with transmitted light appearing as a dark band and with reflected light as a light one. This peculiarity depends upon the presence of air imprisoned between the shrunken and irregular *medullary cells*—dried and cornified epithelial elements which are connected by branching processes into a net-work incompletely filling the medulla. The air within the shaft is a factor modifying the color of the hair, since the resulting reflex tends to lessen the intensity of the tint directly referable to the pigment; this diminution affects particulary the lighter shades, as in dark hairs the large amount of pigment masks the reflex.

FIG. 1156.



Horizontal section of scalp, showing group of transversely cut hair-follicles. × 65.

The Hair-Follicle.—This structure consists essentially of (1) a connective tissue sheath, the *theca*, contributed by the corium; (2) an epithelial lining, the *outer root-sheath*, continued from the deepest layer of the epidermis; and (3) the *inner root-sheath*, an epithelial investment probably differentiated within the follicle, and not a direct prolongation from the cuticle.

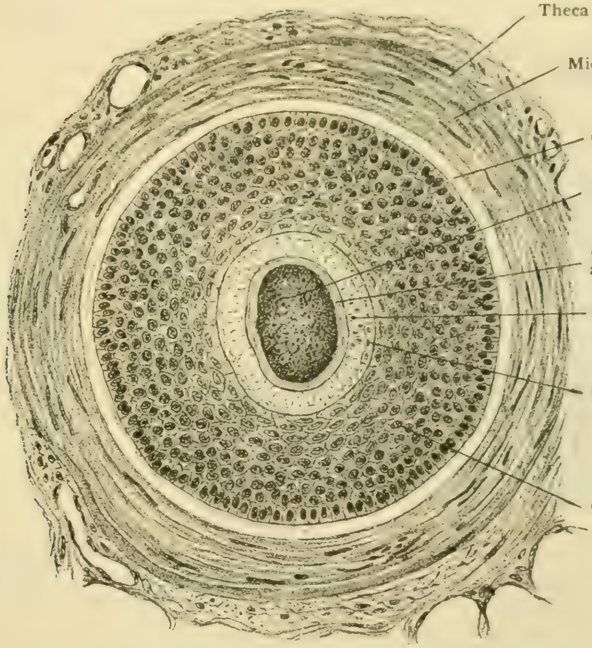
The **theca folliculi** includes three strata: an *outer*, composed of loosely disposed longitudinal bundles of fibrous tissue with few cells and elastic fibres; a *middle* one, made up of closely placed circular bundles; and a very thin, homogeneous *inner* coat, the *glassy membrane*, which represents an unusually well developed

basement membrane separating corium from cuticle. Greatly attenuated, it is prolonged over the hair-papilla, which, as a special vascularized thickening of the connective tissue of the follicle, carries nutrition to the bulb of the growing hair.

The **outer root-sheath** is the continuation of the stratum germinativum alone, the other layers of the epidermis thinning out and disappearing before reaching the neck of the follicle. Its cells present the characteristics of those of the germinating layer, with exceptionally well marked fibrillæ. On approaching the level of the papilla, the outer root-sheath, which farther above consists of numerous layers, rapidly diminishes in thickness until, on the sides of the papilla, it is reduced to a single row of low columnar cells.

The **inner root-sheath**, which is best developed over the middle third of the hair-root and fades away on reaching the upper third, includes three layers. The outer, known as *Henle's layer*, consists of a single row of flat polygonal cells, often partially separated by oval spaces. Their nuclei are very indistinct or invisible

FIG. 1157.



Transverse section of hair-follicle, showing hair surrounded by internal and external root-sheaths. × 285.

within the cornified cytoplasm. The middle or *Huxley's layer*, also horny in nature, often comprises only one stratum of nucleated cuboidal cells, but in the thicker hairs two or even three rows of irregularly interlocked cells may be present. The third layer, known as the *sheath cuticle*, resembles the external coat of the hair, against which it lies, in being extremely thin and composed of flat horny plates. The latter, however, are always nucleated and so disposed that they are opposed to the serrations of the thicker hair-cuticle.

Traced towards the **bottom of the follicle**, the root-sheaths and the hair, which above are sharply defined from one another, become more and more alike until, in the immediate vicinity of the hair-papilla, they blend into a still imperfectly differentiated mass of cells. The deepest elements of this complex, however, are cuboidal or low columnar and form an uninterrupted tract over the papilla, continuous with the outermost cells of the outer root-sheath. It is from the proliferation of these deepest cells that the formative material, or *matrix*, is provided to meet the requirements of growth and replacement of the hairs. Without anticipating the account of the detailed changes described in connection with the development of the hair (page 1401), it may be here noted that of the three parts of the hair, the medulla is produced by

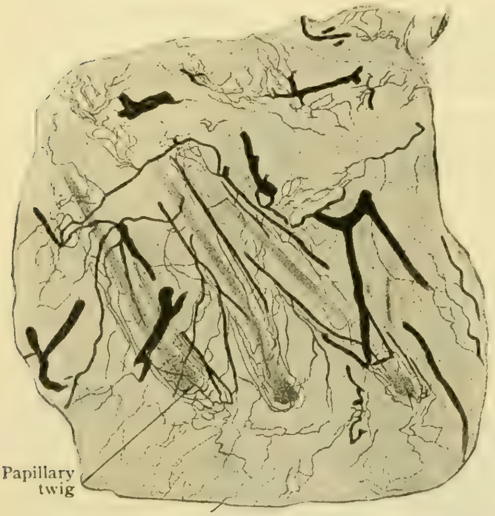
the cells overlying the summit of the papilla, while those converted into the cortical substance, cuticle and inner root-sheath occupy the sides of the papilla and deepest part of the follicle.

With few exceptions, the hair follicles are associated with two or more **sebaceous glands**, rarely with only one, the ducts of which open into the sac in the vicinity of the neck. The glands usually lie on the side towards which the hair inclines, but sometimes, especially in the case of the smaller hairs, they may completely surround the follicle. Since these glands are outgrowths from the same tissue that lines the follicles, their ducts pierce the outer root-sheath, bringing their oily secretion into direct relation with the hairs.

The structure of the sebaceous glands is described with the cutaneous glands (page 1397).

Most of the larger hair-follicles, particularly those of the scalp, are provided with ribbon-like bundles of involuntary muscle, called the **arrectores pilorum** in recognition of their effect on the hairs. They arise from the superficial part of the corium, pass obliquely downward to be inserted into the sheath of the hair-follicle near the junction of corium and subdermal tissue and on the side corresponding with the inclination of the hair and the situation of the sebaceous glands. Since the latter are closely embraced by the muscular bands, contraction of the muscles exerts pressure upon the glands and facilitates the discharge of their secretion (*sebum*)—hence these muscles are sometimes also designated *expressores sebi*. The effect of contraction of the arrectores pilorum is often conspicuously seen on the surface in the condition known as "goose-flesh" (*cutis anserina*), where the hairs and surrounding tissue appear to be unusually elevated owing to the upward pull on the hair-follicles and the consequent erection of the hairs in the opposite direction.

FIG. 1158.



Portion of section of injected scalp, showing capillary net-works surrounding hair-follicles and twigs entering papillæ. × 20.

The **blood-vessels** supplying the hair-follicle, which in a sense constitute a special system for each sac, include the capillary loops ascending within the hair-papilla and the net-work of capillaries surrounding the follicle immediately outside the glassy membrane. The first are derived from a small special twig that ascends to the follicle, and the second from the subpapillary net-work of the corium. With the exception of those draining the papilla, which are tributary to the deeper stems, the *veins* join the subpapillary plexus.

The **nerves** distributed to the follicles follow a fairly definite arrangement. As shown by Retzius, usually each hair-sac is supplied by a single fibre, sometimes by two or more, which approaches the follicle immediately below the level of the mouth of the sebaceous glands. After penetrating the fibrous sheath as far as the glassy membrane, the nerve-fibre separates into two divisions that encircle more or less completely the follicle and on the opposite side break up into numerous fibrillæ constituting a terminal arborization. The nerve-endings usually lie on the outer surface of the glassy membrane within the middle third of the follicle and only exceptionally are found within the outer root-sheath or the hair-papilla.

THE NAILS.

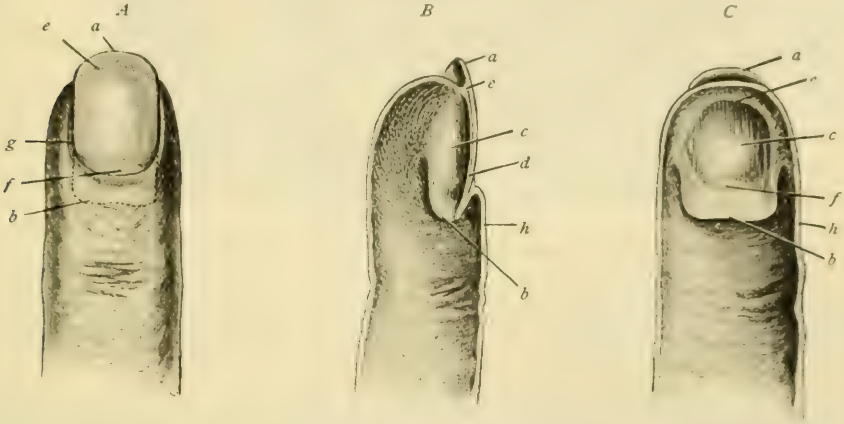
The nails (**ungues**), the horny plates overlying the ends of the dorsal surfaces of the fingers and toes, correspond to the claws and hoofs of other animals and, like them, are composed exclusively of epithelial tissue. They are specializations of the

epidermis and, therefore, may be removed without mutilation when the cuticle is taken off after maceration.

The entire nail-plate is divided into the **body** (**corpus unguis**), which includes the exposed portion, and the **root** (**radix unguis**), which is embedded beneath the skin in a pocket-like recess, the **nail-groove** (**sulcus unguis**). The modified skin supporting the nail-plate, both the body and the root, constitutes the **nail-bed** (**solum unguis**), the cutaneous fold overlying the root being the **nail-wall** (**vallum unguis**).

The sides of the quadrilateral **nail-plate** are straight and parallel and at their distal ends connected by the convex free margin (**margo liber**) that projects for a variable distance beyond the skin. The proximal buried border (**margo occultus**) is straight or slightly concave, more rarely somewhat convex, and often beset with minute serrations (Brunn). Both surfaces of the transversely arched nail are smooth and even, with the exception of the longitudinal parallel ridges that often mark the upper aspect. Inspection of the latter during life shows **color-zones**, the translucent whitish crescent formed by the projecting portion of the nail being immediately followed by a very narrow yellow band that corresponds to the line along which the stratum corneum of the underlying skin meets the under surface of the plate. The

FIG. 1159.



Distal portions of fingers, showing relations of nail; *A* was drawn from living subject; *B* and *C* are lateral and under views respectively of inner surface of cuticle with nail; nothing but the epidermal structures are present, the cuticle and nail having been removed together. *a*, *b*, distal and proximal borders of nail; *c*, under surface of nail; *d*, nail in section; *e*, line of deflection of cuticle to under surface of nail; *f*, lunula; *g*, nail-wall; *h*, cuticle in section.

succeeding and larger part of the nail is occupied by the broad pink zone which owes its rosy tint to the blending of the color of the blood in the underlying capillaries with that of the horny substance. On the thumb constantly, but on the fingers often only after retraction of the cuticle, is seen a transversely oval white area, the so-called *lunula*, which marks the position of the underlying matrix. Additional white spots, irregular in position, form and size, are sometimes seen as temporary markings.

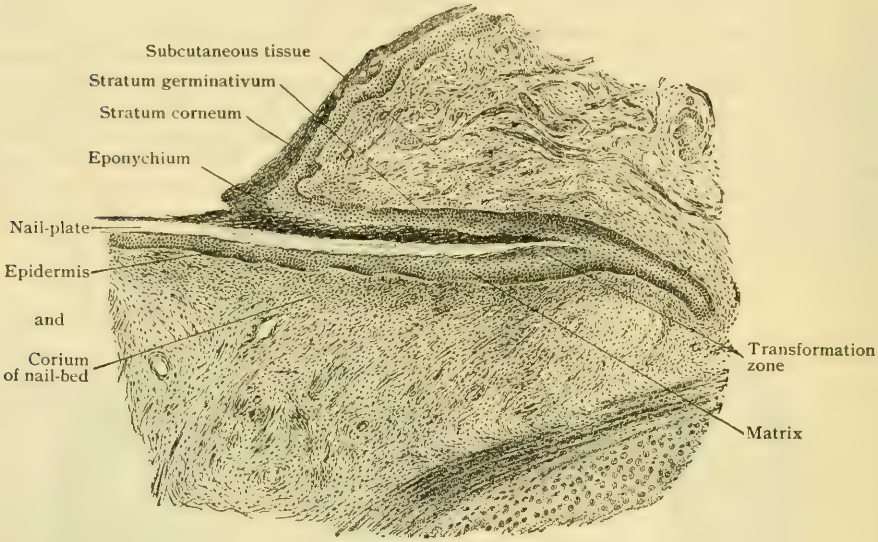
The thickness of the nail-plate—greatest on the thumb and large toe and least on the last digits—diminishes towards the sides, but in the longitudinal direction, between the lunula and the free margin of the nail, is fairly uniform; beneath the white area, however, the under surface of the nail shelves off towards the buried border, where it ends in a sharp edge.

Structure.—The substance of the **nail-plate** (**stratum corneum unguis**) consists entirely of flattened horny epithelial cells, very firmly united and containing the remains of their shrunken nuclei. These cornified scales are disposed in lamellæ, which, in transverse section, pursue a course in general parallel with the dorsal surface. In nails which possess the longitudinal ridges, however, the latter coincide with an upward arching of the lamellæ dependent upon the conformation of the nail matrix (Brunn). In longitudinal section the lamellation is oblique, extending

from above downward and forward, parallel to the shelving under surface beneath the white area that rests upon the matrix. Minute air-vesicles, imprisoned between the horny scales, are constant constituents of the nail-substance. When these occur in unusual quantities, they give rise to the white spots in the nail above mentioned.

Corresponding respectively to the colored zones—the white, rosy and yellow—seen on the dorsal surface of the nail, the **nail-bed** is divided into a proximal,

FIG. 1160.



Longitudinal section of proximal part of nail lying within the nail groove. × 30.

a middle and a distal region, each of which exhibits structural differences. The most important of these regions is the proximal, known as the **matrix**, which lies beneath the white area and alone is concerned in the production of the nail.

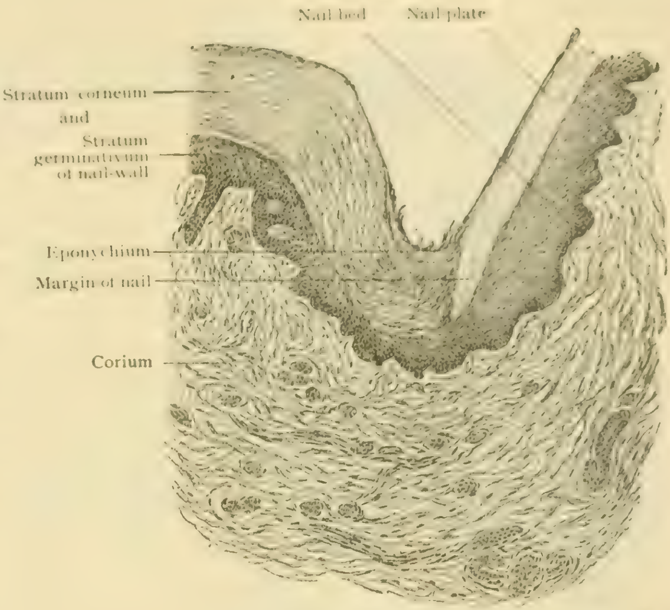
The *corium of the nail-bed* varies in the different regions in the arrangement and size of its elevations. Within the proximal third of the matrix, these elevations occur in the form of low papillæ, which decrease in height and number until they disappear, a smooth field occupying the middle of the matrix. This even field is succeeded by one possessing closely set, low, narrow longitudinal ridges, that at the distal margin of the lunula suddenly give place to more pronounced, but less numerous broader, linear elevations. These continue as far as the distal end of the nail-bed and are then replaced by papillæ. Owing to the strong fibrous bands and the absence of the usual layer of fatty subdermal tissue, the corium of the nail-bed is closely attached to the bone. The fibrous reticulum formed by the interlacing of the longitudinal with the vertical bundles contains few elastic fibres, since these are entirely wanting beneath the body of the nail and only present in meagre numbers within the matrix.

In view of its genetic activity, the relations of the *epidermis underlying the nail* are of especial interest. While the stratum germinativum of the skin covering the finger tip passes directly and insensibly onto the nail-bed, the entire extent of which it invests (**stratum germinativum unguis**), the stratum corneum ends on reaching the under surface of the nail-plate, the line of apposition corresponding to the narrow yellow zone which defines the distal boundary of the rosy area. Beneath the latter, therefore, the epidermis of the nail-bed consists of the stratum germinativum alone, which, without cornification of any of its cells, rests against the under surface of the nail. Beneath the white zone, that is, within the matrix, the epidermis includes a half dozen or more layers of the usual elements of the stratum germinativum, surmounted by a like number of strata of cells distinguished by a peculiar brownish color. On reaching the nail these modified epithelial elements, which appear white by reflected light, are not circumscribed, but pass over into the substance of the nail, into the constituent cells of which they are directly converted. Their cytoplasm presents a marked fibrillation to which, according to Brunn, the light appearance of the cells is referable as an interference phenomenon and not as a true pigmentation. This peculiarity of the cells, coupled with the relatively small size of subjacent capillaries,

probably accounts for the tint distinguishing the white area. Since the transformation of the cells of the stratum germinativum into those of the nail-plate is confined to the matrix, it is evident that the continuous growth of the nail takes place along the floor and bottom of the nail-groove, the last formed increment of nail-substance pushing forward the previously differentiated material and thus forcing the nail towards the end of the digit.

The relation of the *epidermis of the nail-wall* to the substance of the plate is one of apposition only, production of the nail occurring in no part of the fold. Over the greater extent of the latter all the typical constituents of the cuticle are represented, but within the most proximal portion the stratum germinativum alone is present, the stratum corneum fading away. Where the horny layer exists, it rests directly upon the nail, but is differentiated from the latter by being less dense and by its response to stains. As the nail leaves the groove, a part of the stratum germinativum of the nail-wall is prolonged distally for a variable distance over the dorsal surface of the nail-plate as a delicate membranous sheet, the *eponychium*, which usually ends in a ragged abraded border.

FIG. 1161.



Transverse section of nail-wall and adjacent part of nail-plate and nail-bed. × 90.

THE CUTANEOUS GLANDS.

These structures include two chief varieties, the *sebaceous* and the *sweat glands*, together with certain modifications, as the ceruminous glands within the external auditory canal, the circumanal glands, the tarsal and ciliary glands within the eyelid and the mammary glands. In all the epithelial tissues—the secreting elements and the lining of the ducts—are derivatives of the ectoblast and, therefore, genetically related to the epidermis.

The Sebaceous Glands.

Although these structures (**glandulae sebacae**) are chiefly associated with the hair-follicles, in which relation they have been considered (page 1394), sebaceous glands also occur, if less frequently, independently and in those parts of the skin in which the hairs are wanting, as on the lips, angles of the mouth, prepuce and labia minora. The size of these glands bears no relation to that of the hairs, since among the smallest (.2–.4 mm.) are those on the scalp. The largest, from .5–2.0 mm., are found on the mons pubis, scrotum, external ear and nose. Conspicuous aggregations, modified in form, occur in the eyelid as the Meibomian glands.

Depending upon the size of the glands their form varies. The smallest ones are each little more than a tubular diverticulum, dilated at its closed end. In those of larger size the relatively short duct subdivides into several expanded compartments, which, in the largest glands, may be replaced by groups of irregular alveoli, with uncertain ducts that converge into a short but wide common excretory passage.

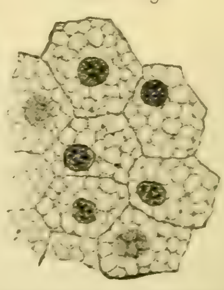
Structure.—The structural components of these glands include a *fibrous envelope*, a *membrana propria* and the *epithelium*, the first two being continuous with the corresponding coverings of the hair-follicle. The **epithelium** continued

into the ducts and alveoli of the sebaceous glands is directly prolonged from the outer root-sheath of the epidermis, where associated with the hair-follicles, or from the epidermis where the hairs are wanting. The periphery of the alveolus is occupied by a single, or incompletely double, layer of flattened and imperfectly defined basal cells, that rest immediately upon the membrana propria and are distinguished by their dark cytoplasm and outwardly displaced oval nuclei. Passing towards the centre of the alveolus, the next cells contain a number of small oil drops which, with each successive row of cells, become larger and appropriate more and more space at the expense of the protoplasmic reticulum in which they are lodged. In consequence, the cells occupying the axis of the alveoli, which are completely filled and without a lumen, contain little more than fat. As the cells are escaping from the glands they lose their nuclei and individual outlines and, finally, are merged as debris into the secretion, or *sebum*, with which the hairs and skin are anointed. The necessity for new cells, created by the continual destruction of the glandular elements that attends the activity of the sebaceous glands, is met by the elements recruited from the proliferating basal cells, which in turn pass towards the centre of the alveolus and so displace the accumulating secretion.

FIG. 1162.

Sebaceous glands from skin covering nose. × 60.

FIG. 1163.



Cells from alveoli of sebaceous gland, showing reticulated protoplasm due to presence of oil droplets. × 700.

THE SWEAT GLANDS.

These structures (**glandulae sudoriferae**), also called the *sudoriparous glands*, are the most important representatives of the coiled glands (**glandulae glomiformes**) often regarded as constituting one of the two groups (the sebaceous glands being the other) into which the cutaneous glands are divided. They occur within the integument of all parts of the body, with the exception of that covering the red margins of the lips, the inner surface of the prepuce and the glans penis. They are especially numerous in the palms and soles, in the former locality numbering more than 1100 to the square centimetre (Horschelmann), and fewest on the back and buttocks, where their number is reduced to about 60 to the square centimetre; their usual quota for the same area is between two and three hundred.

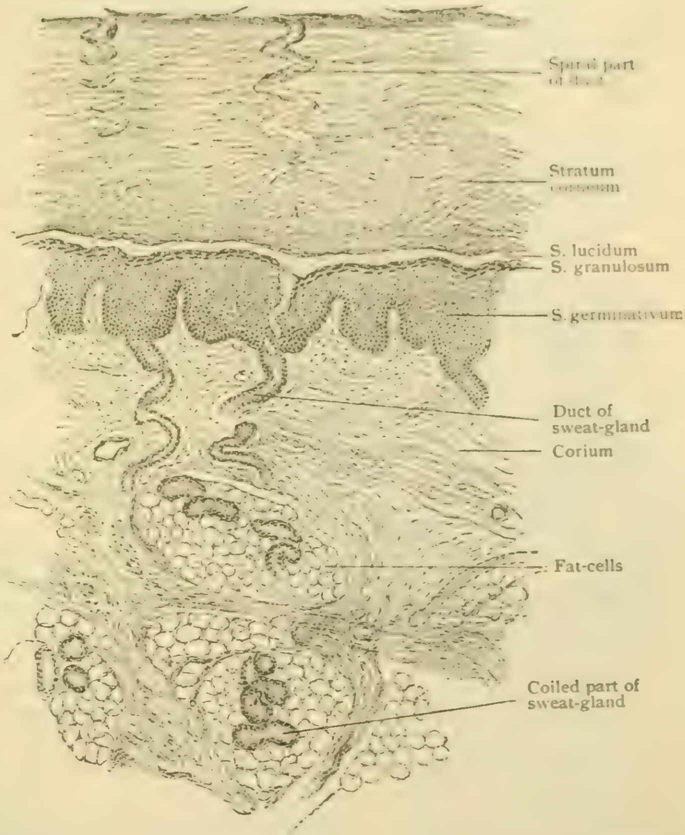
Modified simple tubular in type, each gland consists of two chief divisions, the *body* (**corpus**) or *gland-coil*, the tortuously wound tube in which secretion takes place, and the *excretory duct* (**ductus sudoriferus**) which opens on the surface of the skin, exceptionally into a hair-follicle, by a minute orifice, the *sweat pore* (**porus sudoriferus**), often distinguishable with the unaided eye.

The **body** of the gland, irregularly spherical or flattened in form and yellowish red in color, consists of the windings of a single, or rarely branched, tube and commonly occupies the deeper part of the corium, but sometimes, as in the palm and

scrotum, lies within the subdermal connective tissue. The coiled portion of the gland is not entirely formed by the secretory segment, since, as shown by the reconstructions of Huber, about one fourth is contributed by the convolutions of the first part of the duct.

On leaving the gland-coil, in close proximity to the blind end of the gland, the **duct** ascends through the corium with a fairly straight or slightly wavy course as far as the epidermis. On entering the latter its further path is marked by conspicuous cork-screw-like windings, which, where the cuticle is thick as on the palm, are close and number a dozen or more and terminate on the surface by a trumpet-shaped orifice, the sweat-pore. In its course through the corium the duct never traverses a papilla or ridge, but always enters the cuticle between these elevations. On the palms and soles, where the pores occupy the summit of the cutaneous ridges, the ducts enter the cuticle between the double rows of papillæ.

Fig. 1164.



Section of skin from palm, showing different parts of sweat-glands extending from surface into tela subcutanea. × 65.

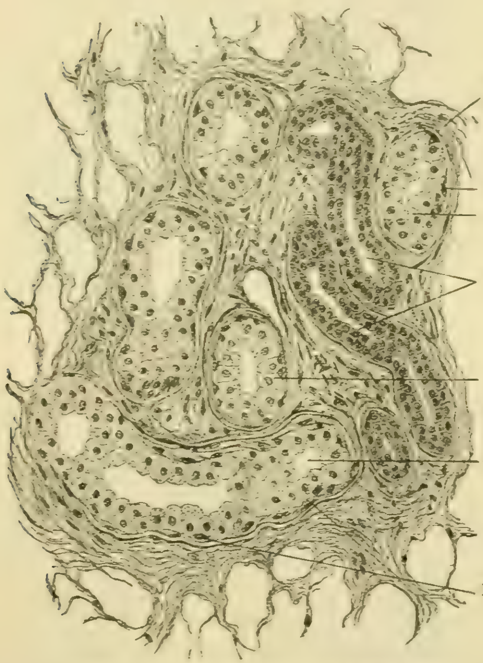
Structure.—The secreting portion of the gland-coil, called the *ampulla* on account of its greater diameter, possesses a wall of remarkable structure. The thin *external sheath*, composed of a layer of dense fibrous tissue and elastic fibres, supports a well defined *membrana propria*. Immediately within the latter lies a thin but compact layer of *involuntary muscle* whose longitudinally disposed spindle-shaped elements in cross-section appear as a zone of irregularly nucleated cells that encircle the secreting epithelium and displace it from its customary position against the basement membrane. This muscular tissue enjoys the distinction, sharing it with the muscle of the iris, of being developed from the ectoblast. The *secreting cells* constitute a single row of low columnar epithelial elements, that lie internal to the muscle and surround the relatively large lumen. Their finely granular cytoplasm contains a spherical nucleus, situated near the base of the cell, and in certain of the larger glands, as the axillary, includes fat droplets and pigment granules. These are liberated with the secretion of the gland and when present in unusual quantity account for the discoloration produced by the perspiration of certain individuals. In the case of the ceruminous glands, the amount of oil and pigment is constantly great and confers the distinguishing characteristics on the ear-wax.

The sudden and conspicuous reduction in the size of the tube which marks the termination of the secreting segment and the *beginning of the duct*, is accompanied by changes in the structure of its wall. In addition to a reduction of its diameter to

one-half or less of that of the ampulla, the duct loses the layer of muscle and becomes flattened, with corresponding changes in the form of its lumen. The single row of secreting elements is replaced by an irregular double or triple layer of cuboidal cells, which exhibit an homogeneous zone, sometimes described as a cuticle, next the lumen. On entering the epidermis, the duct not only loses its fibrous sheath and membrana propria, but the epithelial constituents of its wall are soon lost among the cells of the stratum germinativum, so that its lumen is continued to the surface as a spiral cleft bounded only by the cornified cells of the cuticle.

Apart from mere variations in size, certain glands—the *circumanal*, the *ciliary* and the *ceruminous*—depart sufficiently from the typical form of the coiled glands to entitle them to brief notice. The **circumanal glands**, lodged chiefly within a zone from 12–15 mm. wide and about the same distance from the anus, are not all the same, but include, according to Huber, four varieties. In addition to (1) the usual sweat glands and (2) some (Gay's) of exceptional size, (3) others have relatively straight ducts that end in expanded saccules, from which secondary alveoli arise; finally (4) branched glands of the tubo-alveolar type are present. The **ciliary glands** (**Moll's**) of the eyelid are not typical coiled structures, but belong to the branched tubo-alveolar groups. The **ceruminous glands**, distinguished by the large amount of oil and pigment mingled with their secretion, are likewise referable to the branched tubo-alveolar type.

FIG. 1165.



Section of deeper coiled portion of sweat-gland. × 325.

The **blood-vessels** of the sweat glands include arterial twigs given off from the cutaneous rete, a capillary net-work outside the membrana propria, best developed within the coiled portion of the tube, and the veins that join the deeper plexus within the corium.

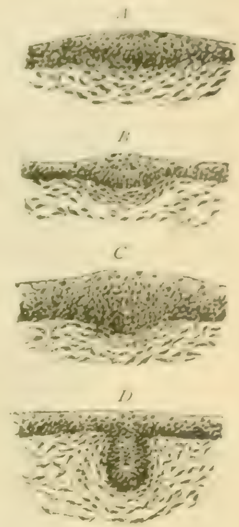
The **nerves** are especially numerous and consist of nonmedullated sympathetic fibres that traverse the fibrous sheath and form a close plexus on the outer surface of the membrana propria. From this net-work fibrillæ penetrate the basement membrane and end in close apposition with the gland-cells and muscle-elements. Their termination on the secreting cells is, according to Arnstein, in the form of peculiar endings consisting of groups and clusters of minute terminal knobs with which the nerve fibrillæ, without or after division, are beset.

THE DEVELOPMENT OF THE SKIN AND ITS APPENDAGES.

The Skin.—The integument consists of two genetically distinct parts—the *epithelium* (epidermis) developed from the ectoblast, and the *connective tissue* (corium and tela subcutanea) from the mesoblast. During the earliest stages of development the ectoblast is represented by a single layer of cells, which, by the end of the first month, is in places reinforced by an external second layer, that by the seventh week has appeared over the entire surface. This double layer now consists

of a deeper row of cuboid or low columnar cells, covered by a superficial sheet, known as the *epitrichium*, composed of flattened elements often lacking in definition, and nuclei. During the succeeding weeks the epitrichial cells become swollen and vesicular and differentiated from the underlying elements, which meanwhile are engaged in producing the **epidermis**. The epitrichium persists until the sixth month, when it becomes loosened and is cast off. During the third and fourth months the ectoblastic cells have so multiplied, that from four to five layers are present, those next the mesoblast being columnar and rich in protoplasm, while the more superficial are irregular and clearer. By the middle of the fifth month, by which time the layers have increased to almost a dozen, the outer cells become horny and assume the characteristics of a *stratum corneum*, while the deepest ones represent the *stratum germinativum*, with an intervening transitional zone. About the sixth month desquamation of the surface cells begins, the discarded epitrichial and other scales mingling with the secretion from the sebaceous glands, which meanwhile have been developed, as constituents of the white unctuous coating, the *vernix caseosa* (**smegma embryonum**), that covers the surface of the fœtus, especially in the folds and creases. During the last weeks of gestation the epidermis acquires considerable thickness and a sharper differentiation of its component strata.

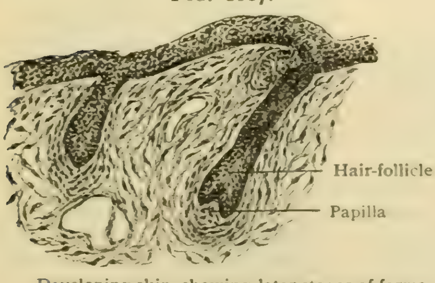
Fig. 1166.



Sections of developing skin, showing earliest stages in formation of hair-follicles; in *D* epithelial cylinder is invading mesoblast. × 90.

The **connective tissue** part of the skin is developed as a superficial condensation of the mesoblast, that during the first month consists of closely placed spindle cells. Coincidently with the appearance of the fibrous fibrillæ, in the third month, differentiation takes place within the condensed mesoblastic tissue, which so far exists as a uniform zone, into a superficial and more compact layer and a deeper and looser one; the former becomes the corium and the latter the tela subcutanea. Within the last layer soon appear larger or smaller groups of round cells in which oil drops, at first minute and then of increasing diameter, indicate the beginning of their conversion into adipose tissue. By the sixth month the panniculus adiposus is established. About the fifth month the line marking the junction of cuticle and corium becomes uneven in consequence of the development of the papillæ and ridges of the corium and the attendant invasion of the epidermis. Certain of the mesoblastic cells are transformed into the component elements of the involuntary muscle that occurs either associated with the hair follicles as the arrectores pilorum, or as the more extended tracts of the dartos.

Fig. 1167.



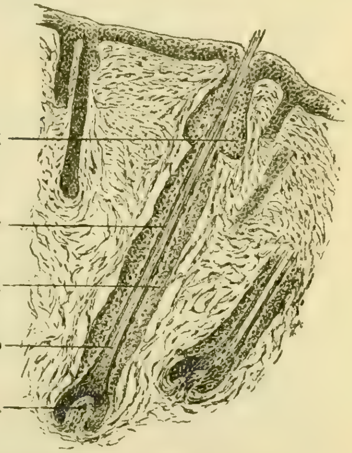
Developing skin, showing later stages of formation of hair-follicles; surrounding mesoblast is forming hair-papilla and fibrous sheath of follicle. × 90.

The Hairs.—The primary development of the hair begins about the end of the third month of fœtal life as localized proliferations of the epidermis. In section these appear as lenticular thickenings and on the surface as slight projections. Very soon solid epithelial cylinders sprout from the deeper surface of these areas and invade the subjacent corium to form the anlages of the *hair-follicles*. The original uniform outline of these processes is early replaced by a flask-shaped contour in consequence of the enlargement of their ends which in their growth surround connective tissue processes to form the *hair-papillæ*. The embryonal connective tissue immediately surrounding the epidermal ingrowth differentiates into the fibrous sheath and the glassy membrane.

Meanwhile and even before the formation of the papilla the epithelial contents of the young follicles differentiate into an axial strand of spindle cells that later undergo keratinization and become the *hair-shaft* that grows by subsequent additions

from the matrix surmounting the papilla. In addition to forming the outer root-sheath the peripheral elements contribute the matrix-cells that occupy the fundus of the follicle and surround the papilla. The cells covering the summit and adjacent sides of the papilla are converted into elongated spindles that later gradually become horny and assume the characteristics of the cortical substance of the hair. When present, the medulla is developed by the transformation of the cells occupying the summit of the papilla, which enlarge, become less granular and grow upward as an axial strand that invades the chief substance of the hair and accumulates keratohyalin within its cells. At first present as minute drops, this substance increases in quantity until it occupies the cells in the form of large vesicles. The subsequent disappearance of these, followed by shrinkage of the cells and the introduction of air, completes the differentiation of the medulla. The pigment particles, which appear later, are first evident in the hair-bulb and probably arise within the epithelial tissue. The elements of the hair-cuticle and of the inner root-sheath are differentiated from the matrix-cells at the sides of the papilla. The tall columnar elements become elongated and converted into the cornified plates of the cuticle both of the hair and of the inner root-sheath. The layers of Huxley and of Henle are derived from cells that soon exhibit granules of keratohyalin, so that on reaching the level of the summit of the papilla the process of cornification has been established. This is especially marked in the elements of Henle's layer, in which the deposit takes the form of a longitudinal fibrillation.

FIG. 1168.



Developing skin, showing later stage of hair-follicle; hair is now differentiated. × 80.

The **growth of the hair** takes place exclusively at the lower end of its bulb, where, so long as the hair grows, the conversion of the matrix-cells into the substance of the hair is continuously progressing. By this process the substance already differentiated is pushed upward by the cells undergoing transformation and these in turn are displaced by the succeeding elements. In this way, by the addition of new increments in its bulb, the hair is forced onward and, in the case of those first formed, through the epidermis that still blocks the mouth of the follicle. This eruption begins on the scalp and regions of the eyebrows about the fifth fœtal month and on the extremities about a month later.

The hairs covering the fœtus are soon shed, during the last weeks of gestation and immediately following birth, and are replaced by the stronger hairs of childhood. These latter, too, are continually falling out and being renewed until puberty, when in many localities, as on the scalp, face, axillæ and external genital organs, they are gradually replaced by the much longer and thicker hairs that mark the advent of sexual maturity. Even after attaining their mature growth, the individual life of the hairs is limited, those on the scalp probably retaining their vitality for from two to four years and the eyelashes for only a few months (Pincus).

During the years of greatest vitality not only are the discarded hairs replaced by new ones, but the actual number of hairs may increase in consequence of the development of additional follicles from the epidermis after the manner of the primary formation. When from age or other cause the hair-follicles loose their productive activity and, therefore, are no longer capable of replacing the atrophic hairs, more or less conspicuous loss of hair results, whether only temporary or permanent evidently depending upon the recuperative powers of the follicles.

The **change of hair** that is continually and insensibly occurring in man, in contrast to the conspicuous periodic shedding of the coat seen in other animals, includes the atrophy of the old hair on the one hand, and the development of the new on the other.

The earliest manifestations of this atrophy, as seen in longitudinal sections of the hair-follicle, are reduction in the size and differentiation of the mass of matrix-cells at the bottom of the follicle and the diminution of the hair-papilla. The progressive reduction of the matrix is

accompanied by the production of a club-shaped enlargement of the hair, between which and the shrunken matrix a strand of atrophic epithelial cells for a time remains. With the continued progress of these changes, the root of the *club-hair*, as the degenerating hair is termed, shortens so that the bulbus enlargement recedes from the bottom of the hair-sac, until it lies just below the narrow neck of the follicle, where it remains for a longer or shorter period until the hair is dislodged and finally discarded. A hair that has fallen out in consequence of these atrophic changes presents well-marked differences in the appearance and structure of its root from a growing hair removed by force. In the discarded hair the root possesses the characteristic club shape, with contours broken by irregular processes composed of the splintered cortical substance, which alone forms the terminal bulb that is always solid and has neither cuticle nor medulla.

FIG. 1169.

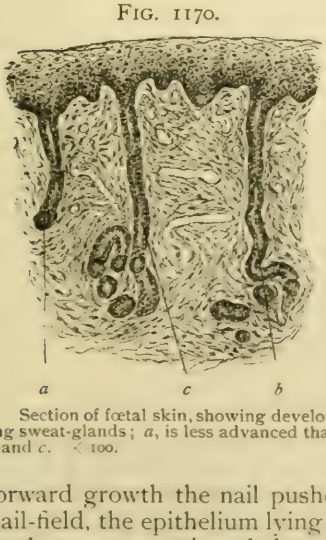
Section of fœtal skin, showing sebaceous gland developing from hair-follicle. × 90.

While the old hair is still lodged in the upper part of the follicle, the first steps towards its replacement are initiated by the stratum germinativum of the old hair-sac. Whether surrounding a new papilla, as held by many, or capping the revived original one (Brunn), the deepest follicle-cells contribute by proliferation the material from which the new hair is developed in a manner agreeing essentially with that in which its predecessor was evolved.

The Nails.—The first appearance of a definite nail-area on the dorsum of the distal phalanx is seen towards the end of the third fœtal month (Kölliker), although Zander has described a local thickening of the epidermis covering the tip of the digit at the ninth week. By the fourth month the **nail-area** shows as a slightly depressed field that is defined proximally and laterally by a curved swelling, the earliest suggestion of the nail-wall. Distally the field is limited by a transverse elevation. Shortly after the nail-area has been thus defined, the outer cells of its stratum germinativum exhibit deposits of keratohyalin which, by the end of the fourth month, lead to the formation of a thin overlying layer of nail-substance. For a time this gains in thickness by additions to its under surface alone, the primary nail being produced by the progressive conversion of the cells of the stratum granulosum, which is present throughout the nail-area.

At this stage the young nail lies completely buried within the epidermis, lying between the most superficial elements of the epidermis and the epitrichial cells above, and the deeper layers of the cuticle below. The overlying epithelial mass, composed of the epidermal and epitrichial elements, constitutes the *eponychium*, the remains of which, after the disappearance of its middle and distal parts, are subsequently seen as a thin membrane covering the proximal part of the nail-plate.

FIG. 1170.



Section of fœtal skin, showing developing sweat-glands; *a*, is less advanced than *b* and *c*. × 100.

As yet the young nail-plate has not come into relation with the epidermis of the nail-groove, since it is still confined to the primitive area. But during the fifth month the proximally growing root invades more and more the sulcus until it attains its definite relations with the nail-wall. Meanwhile the nail-bed beneath the developing root undergoes thickening and becomes the matrix, while the cells containing keratohyalin gradually disappear from the distal region of the nail-area in consequence of their completed conversion into the nail-substance. Subsequently these cells are limited to the proximal nail-producing zone of the matrix from which, after the initial formation of the primary nail-substance, the nail alone receives the additions necessary for its continued growth. In consequence of the resulting forward growth the nail pushes its way through the elevated distal boundary of the nail-field, the epithelium lying above the nail-plate being lost, while that below remains as the representative of the sole-plates that are well marked in many other animals.

The Sweat Glands.—The development of these, the most important members of the group of coiled glands, begins during the fifth fœtal month as solid epithelial sprouts from the under surface of the epidermis. At first cylindrical in form, these processes soon acquire a club-shaped lower end and for a time resemble developing hair-follicles. The terminal segment of the gland-anlage enlarges in diameter and thus early differentiates the later ampulla. With subsequent increase in length, the characteristic coils soon appear, after which a lumen makes its appearance in the ampullary segment and gradually extends to the surface.

Practical considerations of the skin find mention in connection with the various regions, to which the reader is referred.

THE NOSE.

Although only a small part of the nasal chambers is occupied by the peripheral olfactory organ in man, the greater part forming the beginning of the respiratory tract, comparative anatomy and embryology establish the primary significance of the nasal groove and its derivations as the organ of smell, the relation of the nose to respiration being entirely secondary. The nose, therefore, is appropriately grouped with the organs of special sense, notwithstanding its relation to the proper production of voice and to taste and the rôle that it plays in varying facial expression.

The nose consists of two portions, the *outer nose* (**nasus externus**) and the *inner chamber* (**cavum nasi**), which is divided by the median partition into the right and left nasal fossæ

The **outer nose** forms the prominent triangular pyramid that projects from the glabella forward and downward, supported by a bony and cartilaginous framework and covered by muscles and integument. Its upper end or *root* (**radix nasi**) springs from below the glabella from the frontal bone, with which it usually forms an angle and from which, in consequence, it is separated by a groove. When the latter is wanting and the rounded median ridge, or *dorsum*, of the nose continues the plane of the forehead, the nose is said to be of the Grecian type. The dorsum ends below in a free angle or *point* (**apex nasi**), the upper or bony part of the dorsum, often termed the *bridge*, in the aquiline type of nose forming a more or less conspicuous angle with the cartilaginous part.

The sides of the nose (**partes laterales nasi**) descend from the root with increasing obliquity until they reach the broadest part of the nasal pyramid, or *base*, which is pierced by the openings of the *nostrils* or *anterior nares* (**nares**). Just before meeting the base, each lateral surface expands into the mobile and rounded *wing* (**ala nasi**) that forms the outer wall of the nostril and is limited above by a shallow groove, the *alar sulcus*. Under the influence of the attached muscles, the alæ are subject to dilatation, compression, elevation and depression and thereby participate in modifying facial expression.

In addition to the endless minor variations of form that the outer nose presents, which, apart from individual distinction, have little significance, the relation of its greatest breadth across the alæ to its total length, from root to tip, is of sufficient anthropological importance to receive attention in the classification of the races of mankind. This relation, the cephalometric *nasal index* $\left(\frac{\text{greatest breadth} \times 100}{\text{greatest length}}\right)$ varies with different races, according to Topinard the index of the white races being below 70 (*leptorhines*), that of the yellow and red races between 70 and 85 (*mesorhines*), and that of the black races above 85 (*platyrhines*).

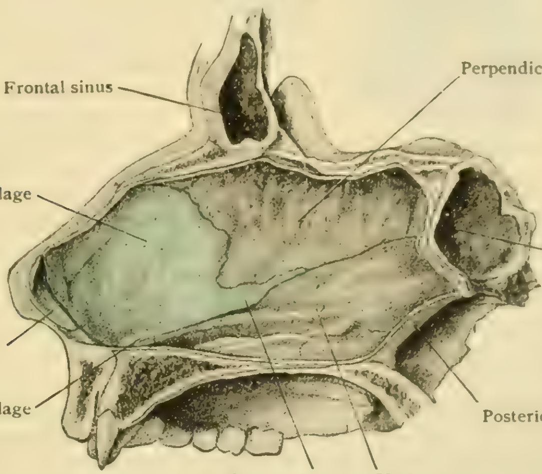
THE CARTILAGES OF THE NOSE.

The cordiform nasal opening (**apertura pyriformis**) of the facial skeleton, bounded by the free margins of the nasal and superior maxillary bones, is enclosed and continued to the anterior nares by the nasal cartilages and contiguous fibrous tissue. These cartilages are usually considered as including five chief plates, the unpaired *septal* and the paired *upper* and *lower lateral*, and a variable number of smaller

supplemental pieces (**cartilagines minores**). The conventional division of the first three, however, is unwarranted, since embryologically and morphologically they constitute one piece (**cartilago mediana nasi**), which even in the adult is represented by the connected septal and upper lateral plates.

The **cartilage of the septum** (**cartilago septi nasi**) (Fig. 1171) completes the median partition that divides the right and left nasal fossæ from each other and represents the anterior extremity of the primordial cartilaginous cranium. It is irregularly rhomboidal in form and so placed that its superior angle lies above, received between the nasal bones and the median plate of the ethmoid, and its inferior angle below, resting upon the incisor crest of the maxillæ. The anterior angle is directed forward and the posterior, much the more pointed, is prolonged as the *sphenoidal process* (**processus sphenoidalis septi cartilaginei**) for a variable distance between the mesethmoid and the vomer towards the body of the sphenoid, which exceptionally it may reach. The antero-superior margin of the septal cartilage, thickest above, is attached to the under surface of the internasal suture for a

FIG. 1171.



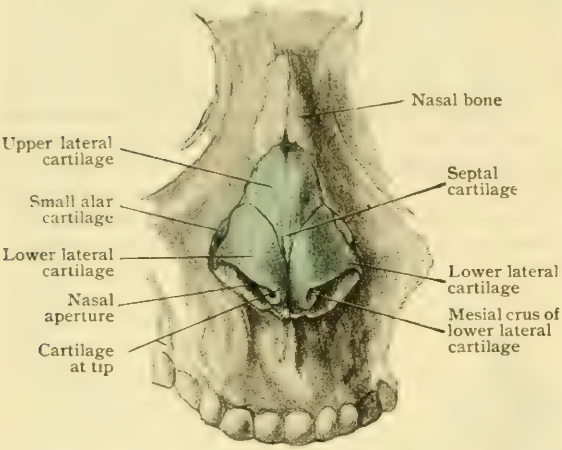
Nasal septum viewed from left side; mucous membrane has been partially removed.

distance of from 12–15 mm. Below the nasal bones, the margin of the septal cartilage is continuous with the upper lateral cartilages which form ring-like expansions (alæ) of the median plate. Still lower, the free-margin of the latter extends between the lower lateral cartilages to within about a half inch from the tip of the nose which, however, it does not reach, the medial crura of the lower lateral plates intervening. The postero-superior margin, the thickest part of the cartilage, is attached to the free margin of the perpendicular plate of the ethmoid bone. The postero-inferior margin rests upon the anterior part of the upper margin of the vomer and the incisive crest as far as the anterior nasal spine, where the border passes into the rounded antero-inferior margin that joins the nasal spine with the anterior angle. This border is always convex and does not reach the lowest part of the partition between the nostrils, which being devoid of septal cartilage, is freely movable and constitutes the *septum mobile*.

The **upper lateral cartilages** (**cartilagines nasi laterales**) (Fig. 1172) are two triangular plates, one on either side, that by their median and longest border are attached to the septal cartilage, with which in their upper part they are directly continuous. The upper margin of each is joined to the free border of the nasal bone, which it slightly underlies, and, exceptionally, the adjacent edge of the maxilla. The lower margin is embedded in fibrous tissue which connects it with the adjoining plates. The median parts of the cartilages are markedly convex and separated by a slight groove that is, for the most part, obliterated by fibrous tissue.

The **lower lateral cartilages** (**cartilagines alares majores**) (Fig. 1172) are a pair of thin curved plates that encircle the apertures of the nostrils anteriorly and constitute the framework of the tip of the nose. Each cartilage consists of an *inner plate* (**crus mediale**), from 6–7 mm. broad, which, with its fellow of the opposite side, embraces the lower and anterior part of the septal cartilage and aids in completing the partition separating the nares. In front it narrows, bends sharply outward, and passes more or less abruptly into a broader *outer plate* (**crus laterale**), which is of very uncertain form and size, although of a general elongated oval shape and some 12 mm. broad. The triangular space between the varyingly prolonged posterior end of the lateral plate, the maxilla and the upper lateral cartilage is filled out by fibrous tissue in which are embedded two, three or more small cartilaginous pieces (**cartilagines alares minores**). These vary greatly in size and form, but in a general way tend to complete the ring of cartilage surrounding the lateral wall of the nares. They do not, however, reach the lower border of the nasal ring, which, as well as the remaining part of the lower boundary of the aperture of the nostril, is devoid of cartilage and composed of integument and fatty connective tissue. The rounded anterior angles of the lower lateral cartilages occupy the tip of the nose, close together when this is pointed, but separated by a space that shows externally as a more or less evident groove when the tip of the nose is blunt and broad. The median plates approach the septal cartilage closer in front than behind, where they curve outward to end in a rounded and upward curving hook. The fibrous tissue uniting the median borders of the lower lateral plates with the anterior edge of the septal cartilage usually contains two small sesamoid cartilages (**cartilagines sesamoideae nasi**) that partly fill the triangular intervals on either side of the median line.

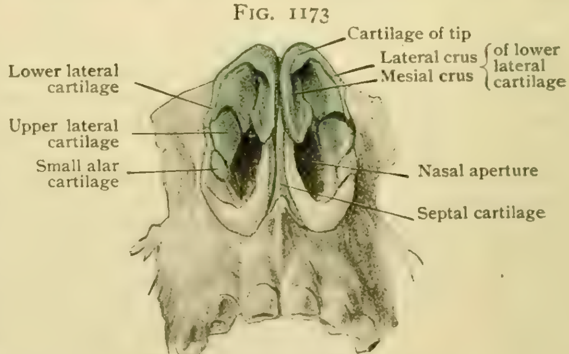
Fig. 1172.



Bony and cartilaginous framework of nose, front aspect.

The **vomerine cartilages** (**cartilagines vomeronasales**) are two narrow strips, from 1–2 mm. wide and from 10–15 mm. long, that lie, one on either side, along the lower border of the septal cartilage in the vicinity of the nasal crest. They are attached to the cartilage and bone by fibrous tissue and situated beneath the mucous membrane lining the nasal fossæ. Their chief interest is their relation to the rudimentary organ of Jacobson (page 1417) below which they lie. In animals in which the organs are well developed these cartilages form protecting and supporting scrolls ; in man, however, both organ and cartilage are so feebly developed that they loose their close relation.

Fig. 1173



Cartilages of nose, viewed from below.

The integument covering the outer nose is in general thin and closely bound down to the underlying fibrous tissue, being particularly unyielding over the tip and alæ. With the exception of within the alæ and lateral borders of the nostrils, the

fatty tissue is very meagre. The sebaceous glands, on the other hand, are well developed and open in many instances in conjunction with the follicles of the delicate hairs that cover all parts of the surface. On the alæ the closely placed glands are of exceptional size and open by ducts readily seen as minute depressions.

Vessels.—In order to compensate for the exposed position, the external nose is generously supplied with *arteries*, derived chiefly from the facial and ophthalmic, which are united by numerous anastomoses with each other as well as with branches from the infraorbital. The *veins* are all tributary to the angular vein, which begins at the inner canthus and descends along the side of the nose to the facial trunk, receiving in its course the dorsal, lateral, and alar branches. The angular vein communicates with the ophthalmic and the veins of the nasal fossa.

The *lymphatics* are arranged in three sets (Küttner). The first, beginning at the root of the nose, passes above the upper eye-lid and along the supraorbital ridge to the parotid nodes. The second group, formed by the superficial and deep lymphatics at the nasal root, skirts the lower margin of the orbit and ends in the lower parotid nodes. The third and most important set includes from 6 to 10 trunks that follow the blood-vessels and end in the submaxillary nodes.

The **nerves** supplying the outer nose include the motor branches of the facial to the muscles and the sensory twigs from the trifacial to the skin, distributed by the infratrochlear and nasal branches of the ophthalmic and by the infraorbital of the superior maxillary.

PRACTICAL CONSIDERATIONS: THE EXTERNAL NOSE.

The *Nose* may be congenitally absent, or bifid, or imperfect, as from absence of the septum or of one nostril, or—very rarely—of both nostrils. As to its external aspect it may be of various types, *e.g.*: Grecian, when the dorsum is on a practically continuous straight line with the forehead, with no marked naso-frontal groove; aquiline, with the dorsum slightly arched; rounded, with the arch much more pronounced; fœtal—"pug"—with the bridge depressed and the nostrils directed somewhat forward.

The fœtal type is simulated in the new born by the subjects of inherited syphilis in whom the bridge of the nose is often much depressed as a result either of (*a*) imperfect development following the severe specific coryza that affects the nasal mucosa and, through the close apposition of the latter to the periosteum of the fragile nasal bones, interferes with their nutrition; or (*b*) by actual caries or necrosis of those bones or of the septum favored by the same conditions. In acquired syphilis the similar nasal deformity is practically always the result of the destruction of the septum, or, less frequently, of the nasal bones, by late (tertiary) lesions.

As a consequence of faulty development in the anterior mid-portion of the frontal bone the membranes of the brain may protrude, forming a meningocele, which is more common at the naso-frontal junction than elsewhere. Occasionally the defect permitting the protrusion exists in the cribriform plate of the ethmoid, and the meningocele occupies the nasal fossa, having under these circumstances been mistaken for a nasal polyp and removed, death resulting from subsequent septic meningitis.

The cosmetic importance of the nose is so great, the diseases producing deformity so frequent, and the susceptibility of the organ to injury so marked, that much ingenuity has been expended upon devices to restore it when lost, or to improve its appearance. In the Tagliacotian operation a cutaneous flap is taken from the arm which is held close to the nose by a complicated dressing until the flap is firmly united in its new position, when its pedicle is detached from the arm. The Indian method is more particularly anatomical, since the flap taken from the forehead is so fashioned that it receives intact the blood from the frontal branch of the ophthalmic artery from the internal carotid, the ophthalmic receiving at the origin of the frontal an important anastomosis from the angular branch of the facial artery, which is given off from the external carotid artery. For partial deformities flaps may be taken from the sides according to the size and situation of the deficiency.

As upon other parts of the face, plastic operations are very successful owing to the free blood supply. Acne rosacea is common on account of the ready response in vascularity of the nose to external irritating influences, and to internal disturbances of the circulation, as from heart and lung disease, chronic gastritis, and alcoholism. Furuncles and superficial infections are frequent because of the number of sebaceous and sweat glands present. Lupus and—in the alar sulcus—rodent ulcers are common because of the constant exposure of the nose to external irritation and to lowering of temperature, depressing its vital resistance. Frost-bite of the nose is also common, especially about the tip, because of its exposed position and the lack of protection to the delicate vessels from overlying tissues.

The nerve supply to the nose is likewise very free, as is shown in a practical manner by the pain which accompanies inflammatory conditions, especially those involving the lower cartilaginous portion where the skin and subcutaneous tissues are very adherent. The resulting exudate is therefore much confined, pressing upon the nerves; this accounts also for the frequency with which gangrene occurs under these circumstances.

Watering of the eyes from irritation of the skin or mucous membrane of the nose is due to the free nerve supply, and to the fact that the same nerve, the trigeminal, supplies the nose and the lachrymal apparatus; as a portion of the nasal chamber is supplied by a branch of the ophthalmic nerve, raising the eyes to the sun will often give the added irritation necessary to precipitate a sneeze when the nasal stimulus suggests one, but is not quite strong enough unaided. Cough and bronchial asthma have resulted from nasal affections due to the indirect relations between the fifth cranial nerve and the pneumogastric. As the olfactory portion of the nasal fossa is in the upper portion of the cavity, an earnest effort to recognize an odor or to enjoy one to the utmost, is accompanied by a deep inspiration through the nose with dilatation of the nostril. In paralysis of the facial nerve, the involvement of the dilatores naris has been thought to explain the lessening of the olfactory sense sometimes seen in this condition. Paralysis of the levatores alæ nasi muscles has permitted the nostrils to close during inspiration, causing stridor and mouth-breathing. The loss of the sense of smell is a not uncommon result of severe blows, especially on the forehead, and may be due to (*a*) concussion of the olfactory bulbs; (*b*) fracture of the cribriform plate of the ethmoid; (*c*) injury to the olfactory roots where they cross the lesser wing of the sphenoid; or (*d*) lesion of the olfactory nerves where they traverse the cribriform foramina. Sneezing from irritation of the nose is probably due to the indirect relationship between the fifth pair and the vagus and may be so violent that serious injury may result, as in cases in which a subcoracoid luxation of the shoulder, a fracture of the ninth rib, and the rupture of all the coverings of a large femoral hernia were produced by this act (Treves).

The abundant sweat and sebaceous glands in the skin of the nose account for the frequency with which acne vulgaris attacks it. The alæ, the only movable portions, take part in the movements of expression, as in contempt and scorn.

Fractures of the nose are common because of its exposed position, and of the frequency of blows and other forms of violence applied to the face. Their chief importance depends upon the prominence of the nose as a feature of the face, any change in its shape attracting general attention. The fracture occurs most commonly in the lower part, because of the greater weakness of the bones and their greater prominence at that level. In its upper part, the relative depression of the dorsum, the greater thickness of the bones, and their more firm support, make fracture less common. On the other hand, the higher fractures are more dangerous because of their possible relation with the cribriform plate and sinuses of the ethmoid bone, the frontal sinuses and the nasal duct. Involvement of the cribriform plate is in effect a compound fracture of the base of the skull, exposing the meninges to the danger of infection. Fractures of the nose are almost always compound, because of the intimate adhesion of the mucous membrane to the bone, with little intervening tissue, so that when the bone breaks the overlying adherent tissue is torn through. This accounts for the practically uniform occurrence of epistaxis, on account of which it is often difficult to detect the presence of escaping cerebro-spinal fluid when the

cribriform plate is also fractured. On the other hand, the rich glandular supply of the mucous membrane, which makes the usual mucous secretion exceptionally free, may, in a post-traumatic coryza, result in a watery discharge of such quantity as to suggest the escape of the cerebro-spinal fluid. Emphysema within the orbit and under the skin may result from the communication of the nose with the ethmoidal or frontal sinuses. In the effort to keep the nose clear of blood by blowing, the air is forced into the subcutaneous tissues.

In fractures at the lower part, the deformity is frequently lateral, because of the greater exposure to side blows, and the tendency of the cartilaginous alæ and septum to avoid crushing. In the upper part depression is more likely, because of the tendency to escape any but forces from in front, the greater force necessary to produce the fracture, and the presence of a bony septum underneath, which crushes rather than bends.

When the deformity has been replaced there are no strong muscles to reproduce it, so that little or no effort is necessary to maintain the fragments in position. The deformity must be reduced early and the reduction maintained, because owing to the free blood supply, union is usually rapid, sometimes occurring in a week. One must bear in mind in reducing the deformity that the roof of each nasal fossa is not more than 2–3 mm. wide, and that, therefore, a narrow rigid instrument is necessary to press the fragments upward into their normal positions.

THE NASAL FOSSÆ.

The cavity of the nose is divided by the median septum into two nasal fossæ which extend from the anterior to the posterior nares, or *choanæ*, through which they open into the naso-pharynx. They communicate more or less freely with the accessory air-spaces within the frontal, ethmoid, sphenoid and maxillary bones, into which, as a lining, the mucous membrane of the nasal fossæ is directly continued.

Seen in frontal section (Fig. 1176), each fossa is triangular in its general outline, the apex being above at the narrow roof and the base below on the floor. The smooth median wall is approximately vertical and meets the floor at almost a right angle, while the sloping lateral wall is modelled by the projecting scrolls of the three turbinates, which overhang the corresponding meatuses. In sagittal sections (Fig. 1174) the contour of the fossa resembles an irregular parallelogram from which the upper front corner has been cut off, so that in front the upper border slopes downward to correspond with the profile of the outer nose. The greatest length of the fossa, measured along the floor, is from 7–7.5 cm. (2¾-3 in.) and its greatest height from 4–4.5 cm. The width is least at the roof, where it is less than 3 mm., and greatest in the inferior meatus a short distance above the floor, where it expands to from 15–18 mm.

The Vestibule.—The anterior part of the fossa, immediately above the opening of the nostril and embraced by the outer and inner plates of the lower lateral cartilage and adjoining portion of the septum, is somewhat expanded and constitutes the *vestibule* (**vestibulum nasi**), a pocket-like recess prolonged towards the tip being the *ventricle* (**recessus apicis**). These spaces are lined by delicate skin, directly continuous with the external integument and tightly adherent to the underlying cartilage, and, in the lower half of the vestibule, containing numerous sebaceous glands and hairs. In the vicinity of the nostril the hairs, known as *vibrissæ*, are coarse and long and curved downward to afford protection to the nasal entrance. Over the upper part of the vestibule, the skin is smooth and closely attached to the lower lateral cartilage, the upper margin of the outer plate projecting as a slightly arching ridge, the *limen vestibuli*, which forms the superior and lateral boundary of the vestibule and marks the line of transition of the skin into the mucous membrane that lines the remaining parts of the nasal fossa.

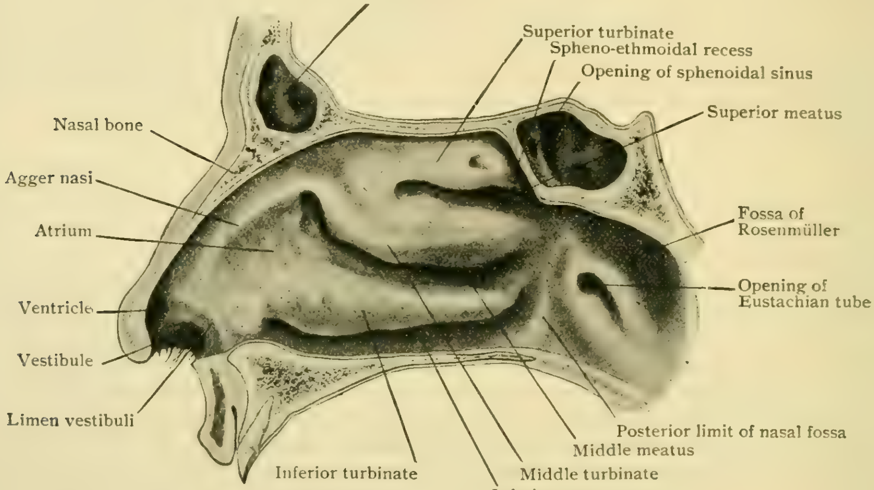
Above and beyond the vestibule, the nasal fossa rapidly expands into a triangular space, the *atrium nasi*, that lies in advance of the entrance into the middle nasal meatus. Above and in front the atrium is bounded by a low and variable ridge, the *agger nasi*, that represents a rudimentary naso-turbinate, which in many mammals attains a large size. The space lying in front of the agger, extending

from the limen to the cribriform plate of the ethmoid and roofed in by the forepart of the arched upper boundary of the fossa, is long and narrow in consequence of the approximation of the median and lateral walls. It leads from the nasal aperture to the summit of the nasal fossa and to it Merkel applied the name *carina nasi.*

The Nasal Septum.—The median wall consists of the partition formed chiefly by the perpendicular plate of the ethmoid, the vomer and the septal cartilage, covered on both sides by mucous membrane. The extreme lower and anterior part of the septum, consisting of the alar cartilage and the integument, is flexible, and therefore called the *membranous portion*, or *septum mobile;* the terms *bony* and *cartilaginous portions* are applied to the remaining parts of the septum supported by bone and cartilage respectively.

While during early childhood its position is median, in the great majority of adults the septum presents more or less asymmetry and lateral deflection, most often

FIG. 1174.



Right nasal fossa, lateral wall; and naso-pharynx.

to the right. This deviation may affect the septal cartilage alone, may be limited to the bones (in 53 per cent. according to Zuckerkandl), or may be shared by both. The most common seat of the deflection is the junction of the ethmoid and vomer, in the vicinity of the spheno-ethmoidal process, or along the union of the vomer and the septal cartilage. The asymmetry may involve the entire septum, which then is oblique; or it may take the form of a simple bulging towards one side, a double or sigmoid projection; or be an angular deflection resembling a fold, crest or spur that projects into one, sometimes both, of the fossæ (Heymann).

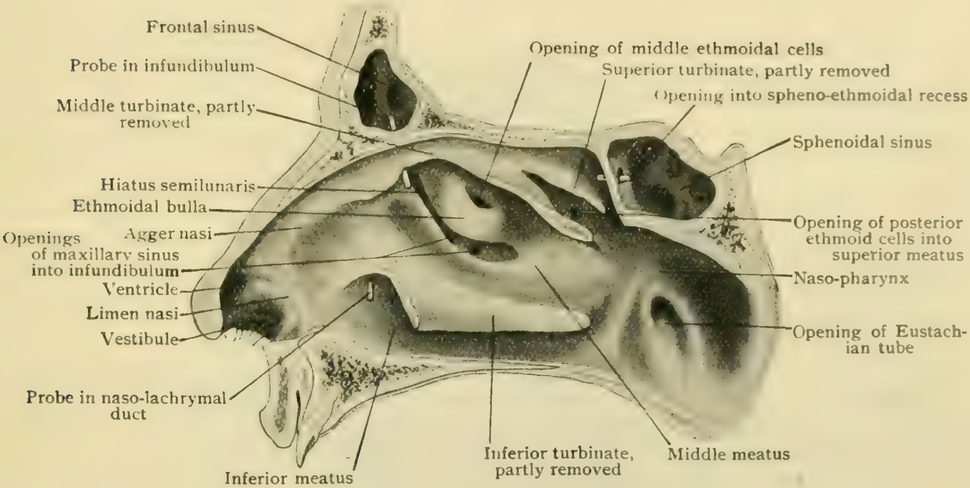
Although the mucous membrane covering the nasal septum is generally smooth and of fairly constant thickness, its surface is marked by inequalities caused chiefly by variations in the amount and development of the glandular and vascular tissue. One such accumulation, the *tuberculum septi*, is relatively constant and on the septum about opposite the anterior end of the middle turbinate. During early life a series of from four to six or more oblique ridges, *plicæ septi*, often model the lower and posterior part of the septum, extending from below upward and forward. Slightly above the anterior nasal spine, the septal mucosa presents the minute openings leading into the rudimentary organ of Jacobson. Behind, the margin of the bony septum is covered by mucous membrane of unusual thickness which, therefore, forms the immediate free edge of the partition separating the posterior nares.

The Lateral Wall.—The lateral wall of the nasal fossæ is characteristically modelled by the projecting scrolls (**conchae nasi**) of the three turbinates. The latter partly subdivide each fossa into three lateral recesses, the *superior*, *middle*, and

inferior meatuses. These are overhung by the corresponding bony concha, the superior meatus being roofed in by the upper turbinate and the inferior lying between the lower turbinate and the floor of the fossa. That part of the nasal fossa between the conchæ and the septum, into which the recesses open medially, is sometimes called the *meatus nasi communis*. The details of the nasal fossa as seen within the macerated skull have been described in connection with the skeleton (page 223). In the recent condition, when the soft parts are in place, while their general contour is preserved, the compartments of the fossæ are materially reduced in size by the thickness of the mucous membrane and the erectile tissue that cover the bony framework.

The Superior Meatus.—Corresponding to the small size of the upper turbinate, the superior meatus (**meatus nasi superior**), or *ethmoidal fissure*, is narrow and groove-like and little more than half the length of the middle one. It is directed downward and backward and is floored by the convex upper surface of the middle concha. When the upper turbinate is replaced by two scrolls (conchæ superior et suprema)—a condition that Zuckerkandl regards as very frequent, if indeed, not the more usual—the meatus is accordingly doubled. Into the upper and front part of the superior meatus the posterior ethmoidal air-cells open by one or more orifices

FIG. 1175.



Lateral wall of nasal fossa; portions of turbinate bones have been removed to expose openings into air spaces.

of variable size. Above and behind the upper turbinate and in front of the body of the sphenoid bone lies a diverticulum, the *spheno-ethmoidal recess*, into the posterior part of which opens the sphenoidal sinus.

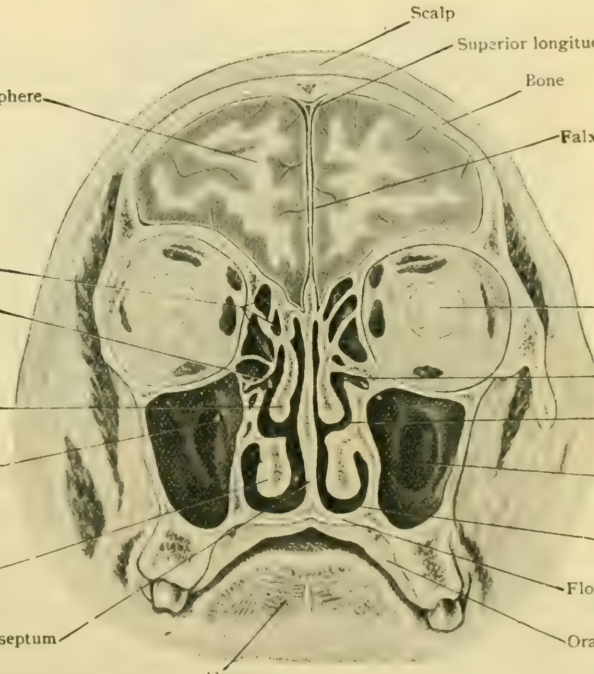
The Middle Meatus.—The recess beneath the middle turbinate (**meatus nasi medius**) is spacious and arched to conform with the contour of the middle and inferior conchæ which constitute its roof and floor respectively. On elevating, or still better removing close to its attachment, the middle turbinate bone, a deep crescentic groove, the *infundibulum*, is seen on the outer wall of the fossa overhung by the anterior half of the concha. The crescentic cleft leading from the middle meatus into the infundibulum is the *hiatus semilunaris*,[1] which extends from above downward and backward, with its convexity directed forward. Its anterior boundary is a sharp crescentic ridge due to the uncinate process of the ethmoid covered with thin mucous membrane, while behind it is limited by a conspicuous elevation produced by the corresponding underlying bony projection of the ethmoidal bulla.

[1] Some confusion exists in the use of this term, since it is often applied to the entire groove and not merely to the cleft which leads from the meatus into the groove. The name is here employed as indicating the lunate cleft and not the groove (which is the infundibulum), as originally used by Zuckerkandl, who introduced it. See Antomie der Nasenhöhle, Wien, 1882, page 39.

When the infundibulum does not end blindly above, which it often does (page 194), its upper extremity, usually somewhat expanded, receives the opening of the frontal sinus, *ostium frontale.* The sinus is, however, not dependent upon the infundibulum for its communication with the middle meatus, since, as pointed out by Zuckerkandl, between the front of the attachment of the middle turbinate bone and the uncinate process of the ethmoid there exists a passage which leads to the ostium frontale. Into the upper part of the infundibulum usually open some of the anterior ethmoidal air-cells ; lower in the groove lies the oval or slit-like *ostium maxillare*, the chief communication of the antrum of Highmore. When the latter is provided with an additional orifice, as it is in 10 per cent. (Kallius), the smaller accessory communication opens into the infundibulum a few millimeters behind the principal aperture. Above the hiatus semilunaris, either on or above the bulla, is usually seen the slit-like opening through which the middle ethmoidal cells communicate with the meatus.

The Inferior Meatus.—This passage (**meatus nasi inferior**), the largest of the three, measures from 4.5–5.5 cm. in length, its anterior end lying from 2.5–3.5 cm. behind the tip of the nose. At first relatively contracted, it abruptly expands, not

FIG. 1176.



Frontal section of head, viewed from behind, showing nasal fossæ and communications with frontal and maxillary sinuses.

only in height, in correspondence with the arched attached border of the lower turbinate, but also in width. Farther backward, it gradually diminishes and is again reduced at its choanal end. On the lateral wall of the inferior meatus, usually from 3–3.5 cm. behind the posterior margin of the nostril, after removal of the lower turbinate, may be seen the opening of the naso-lachrymal duct. The position and form of the orifice are subject to much variation. When close to the arching attached border of the concha, the aperture is usually oval or even round ; when its position is lower, it is narrow and slit-like, obliquely vertical, and often guarded by a fold of mucous membrane, the so-called *valve* of *Hasner.*

The arched **roof of the nasal fossa** is divisible into a naso-frontal, an ethmoidal and a sphenoidal part in accordance with the bones over which the

mucous membrane stretches. The lower part of the naso-frontal division, below the nasal bone, is cutaneous and cartilaginous. Anteriorly the roof is reduced to little more than a groove on account of the approximation of the lateral and median walls, but posteriorly broadens towards the choana. The median part of the roof, formed by the cribriform plate of the ethmoid, is very thin and makes a sharp angle with the steeply descending sphenoidal division. Between the latter and the superior turbinate bone lies the spheno-ethmoidal recess.

The **floor of the nasal fossa**, much broader than the roof and supported by the palatal process of the maxilla and the horizontal plate of the palate bone, from before backward is approximately horizontal, but from side to side is distinctly concave. Anteriorly this wall is robust, but rapidly diminishes in thickness as it passes backward. About 2 cm. behind the posterior margin of the nostril and close to the septum, the floor of each nasal fossa presents a slight depression, sometimes narrow and funnel-shaped, that leads into a small canal lined with a prolongation of mucous membrane. This canal converges towards the septum with its fellow of the opposite fossa, descends almost vertically, and passes through the incisive foramen in the hard palate to end on the roof of the mouth as a minute slit at the side of the incisive pad or papilla palatina. Although the two tubes of mucous membrane may join to form a single *incisive canal*, they usually retain their independence (Lebouecq, Merkel). They are often closed and impervious; sometimes, however, even in the adult communication is retained between the nasal and oral cavities.

The **posterior nares** or **choanæ**, the apertures through which the nasal fossæ communicate with the naso-pharynx, one on either side of the septum, resemble in form somewhat a Gothic arch (Fig. 1354). They are relatively much lower in the new-born child than in the adult, in which they measure about 3 cm. in height and 1.5 cm. in breadth (Zuckerkandl), although individual variation is considerable. Each opening is bounded below by the horizontal plate of the palate bone; laterally by the inner surface of the internal pterygoid plate of the sphenoid; above by the vaginal process of the sphenoid and the ala of the vomer; and mesially by the vertical posterior borders of the vomer. Over this bony arch the nasal mucous membrane is continuous with that lining the pharynx. Laterally the posterior limit of the nasal fossa in the recent condition is indicated by a furrow (**sulcus nasalis posterior**) that extends from the under surface of the sphenoid downward to about the junction of the hard and soft palates. Behind this furrow, about on a level with the lower border of the inferior turbinate, lies the opening of the Eustachian tube (Fig. 1174). Since the turbinates end approximately 12 mm. in advance of the choanæ, the outlines of these openings are unbroken by the scrolls that model the lateral wall of the nasal fossæ, all three conchæ, however, being visible through the posterior nares.

THE NASAL MUCOUS MEMBRANE.

Beyond the limen that marks the limit of the integument clothing the vestibule (page 1409), the nasal fossa is lined by mucous membrane continuous with that of the naso-pharynx through the choanæ. Since in addition to lining the tract over which the respired air passes the nasal mucous membrane contains the cells receiving the impressions giving rise to the sense of smell, it is appropriately divided into a *respiratory* and an *olfactory* part.

The Olfactory Region.—The highly specialized regio olfactoria is quite limited in extent and embraces an area situated over the middle of the upper turbinate and the corresponding part of the septum. According to Brunn,[1] whose conclusions are here presented, the olfactory area of each fossa includes only about 250 sq. mm., the septum contributing something more than one-half of the entire surface. Accordingly the specialized field is by no means coextensive with the upper turbinate bone, as it reaches neither its lower nor posterior border (Fig. 1177). The anterior margin of the area, which lies about 1 cm. behind the front wall of the nasal fossa, is irregular in outline owing to the invasion of the specialized region by the adjacent

[1] Archiv f. mikros. Anat., Bd. 39, 1892.

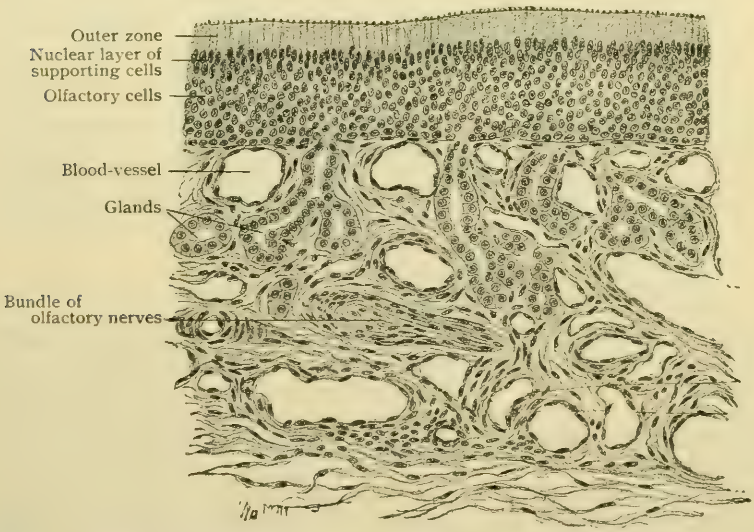
respiratory mucous membrane, tongues or even islands of the latter projecting into or being surrounded by the former. Upon the evidence derived from careful dissection of the olfactory mucous membrane, however, it is difficult to avoid the conclusion that Brunn's areas are too limited, as nerve-filaments clearly attached to the olfactory bulb are usually traceable onto the upper part of the middle turbinate bone. In fresh preparations the olfactory area usually, but not always, can be approximately mapped out by the yellowish hue, lighter or darker, that distinguishes it from the respiratory region in which the mucous membrane exhibits a rosy tint.

FIG. 1177.

Right nasal fossa, septum (s) has been partially separated and turned upward; dark field shows olfactory area on lateral and mesial walls of fossa, as mapped out by *Brunn*..

The **epithelium** contains two chief constituents—the supporting and the olfactory cells. The *supporting cells* are tall cylindrical elements, about .06 mm. in height, that extend the entire thickness of the epithelium. Their outer and broader ends are of uniform width and contain the oval nuclei which, lying approximately at the same line and staining readily, form a deeply colored and conspicuous nuclear stratum at some distance beneath the free margin. Between the latter and the row of nuclei, the epithelium presents a clear zone devoid of nuclei. The inner part of the supporting cells is thinner and irregular in contour and often terminates by splitting into two or more basal processes that rest upon the tunica propria. Between these ends lie smaller pyramidal elements, the *basal cells*, that

FIG. 1178.



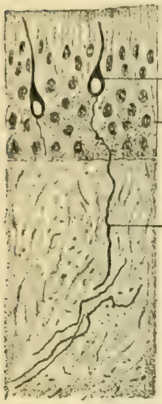
Section of olfactory mucous membrane; epithelium displays outer nuclei-free and nuclear layers formed by supporting cells and broad stratum containing nuclei of olfactory cells. × 300.

probably represent younger and supplementary forms of the sustentacular cells. The granular protoplasm of the basal processes often contains pigment particles.

The **olfactory cells**, the perceptive elements receiving the smell-stimuli, consist of a fusiform body, lodging a spherical nucleus enclosed by a thin envelope of cytoplasm, and two attenuated processes, a peripheral and a central. The olfactory cells are in fact sensory neurones that have retained their primitive position within the surface epithelium, as in many invertebrates, instead of receding, as is usual in

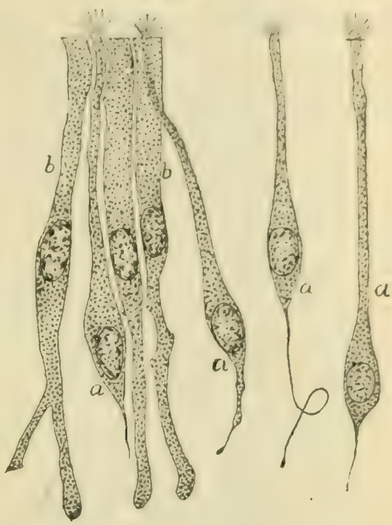
the higher animals, to situations more remote from the exterior. The slender peripheral process of the olfactory cell, which corresponds to the dendrite of the neurone, is of uniform thickness and ends at the surface in a small hemispherical knob that projects slightly beyond the general level of the epithelium and bears from 6–8 minute stiff cilia, the *olfactory hairs.* The length of the peripheral processes, being dependent upon the position of the nuclei, varies, since the latter occupy different levels within the epithelium in order to accommodate their greater number—about 60 per cent. in excess of those of the supporting cells (Brunn). The central

FIG. 1179.



Section of human olfactory mucous membrane, silver preparation; two olfactory cells are seen, one of which sends nerve-fibre towards brain. × 335. (*Brunn.*)

FIG. 1180.



Isolated elements of epithelium of olfactory mucous membrane; *a*, olfactory cells; *b*, supporting cells. × 1000. (*Brunn.*)

processes of the olfactory cells, much more delicate than the peripheral, are directly continued, as the axis-cylinders, into the subjacent nonmedullated nerve-fibres within the tunica propria, from which they pass through the cribriform plate to enter the brain and end in the arborizations within the olfactory glomeruli of the bulbus olfactorius (page 1152).

The **tunica propria** is differentiated into a superficial and a deep layer by the adenoid character of the stratum immediately beneath the epithelium. The superficial layer, from .015–.020 mm. thick, consists of closely packed irregularly round cells, resembling lymphocytes, and meagre bundles of delicate connective tissue. The deep layer, on the other hand, contains robust bundles of fibro-elastic tissue and relatively few cells. A distinct membrana propria is wanting within the olfactory region.

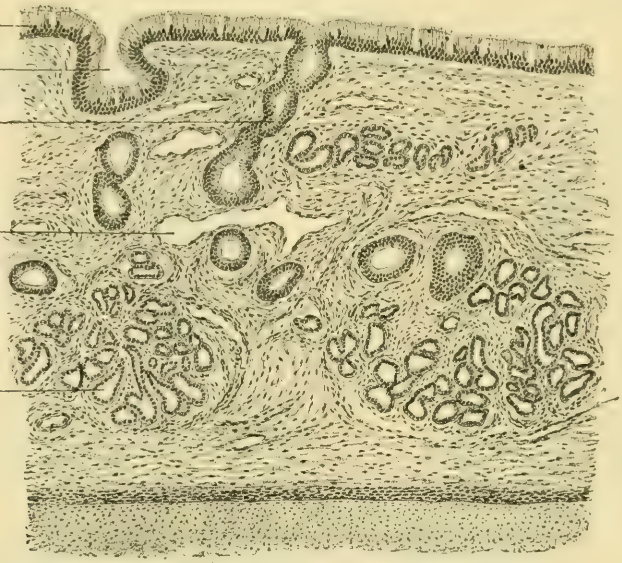
The **glands of Bowman** (**glandulae olfactoriae**) are characteristic of the olfactory region and probably elaborate a specific secretion (Brunn). They open onto the free surface by very narrow ducts that lead into saccular fusiform dilatations, into which the tubular alveoli open. The ducts possess an independent lining of flattened cells that extend as far as the surface and lie between the surrounding epithelial elements. The dilatations are clothed with flattened or low cuboidal cells, which are replaced by those of irregular columnar or pyramidal form within the tubular alveolar. From the character of their secretion the glands of Bowman are probably to be reckoned as serous and not mucous (Brunn, Dogiel).

The Respiratory Region.—The mucous membrane lining of the respiratory region differs greatly in thickness in various parts of the nasal fossa. In situations where the contained cavernous tissue is well represented, as over the inferior turbinate, it may reach a thickness of several millimeters, while when such tissue is wanting, as on the lateral wall, it is reduced to less than a millimeter.

The **epithelium** is stratified ciliated columnar in type, from .050 – .070 mm. thick, and includes the tall surface cells, bearing the cilia, between the inner ends of which lie the irregularly columnar basal cells. Numerous elements exhibit various stages of conversion into mucous-containing goblet cells. The current produced by the cilia is toward the posterior nares.

Beneath the epithelium stretches the membrana propria or basement membrane, that varies greatly in thickness; although in certain localities feebly developed, it is usually well marked and measures from .010 – .020 mm. in thickness (Brunn).

FIG. 1181.



Section of respiratory mucous membrane covering nasal septum. × 75.

Under pathological conditions its thickness may increase fourfold or more. In many places the membrana propria is pierced by minute vertical channels, the *basal canals*, in which connective-tissue cells and leucocyctes are found, but never blood-capillaries (Schiefferdecker).

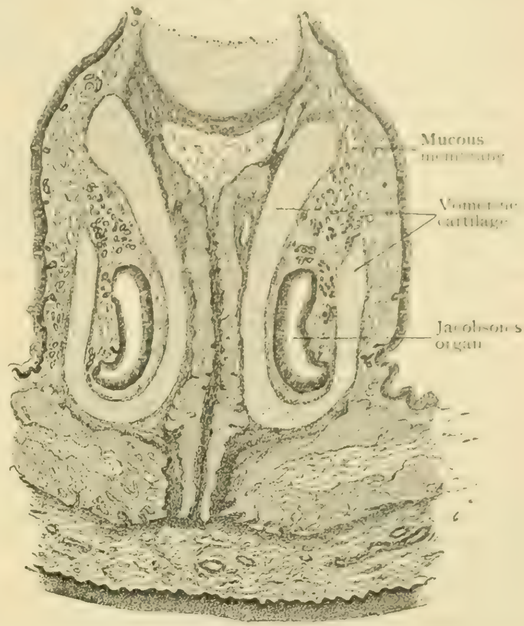
The **tunica propria** consists of interlacing bundles of fibro-elastic tissue which are most compactly disposed towards the subjacent periosteum. The looser superficial stratum is rich in cells and here and there contains aggregations of lymphocytes that may be regarded as masses of adenoid tissue (Zuckerkandl). In certain parts of the nasal fossa the stroma of the mucous membrane contains vascular areas composed of numerous intercommunicating blood-spaces that confer the character of a true cavernous tissue. These specialized areas, the *corpora cavernosa*, as they are called, are especially well developed over the inferior and the lower margin and posterior extremity of the middle conchæ, and less so over the posterior end of the upper turbinate and the tuberculum septi. When typical, they occupy practically the entire thickness of the mucous membrane from periosteum to epithelium, the interlacunar trabeculæ containing the glands and blood-vessels destined for the subepithelial stroma. The blood-sinuses, the general disposition of which is vertical to the bone (Zuckerkandl), include a superficial reticular zone of smaller spaces and a deeper one of larger lacunæ. The engorgement and emptying of the cavernous tissue is controlled by nervous reflexes and probably has warming of the inspired air as its chief purpose (Kallius).

The **glands** of the respiratory region are very numerous, although varying in size, tubo-alveolar in form and, for the most part, mixed mucous in type. The chief ducts open on the free surface by minute orifices barely distinguishable with the unaided eye. Their deeper ends branch irregularly into tubes that bear the ovoid terminal alveoli. The latter are lined with mucous-secreting cells, between which lie

the crescentic groups of serous cells that stamp the glands as mixed (Stöhr). Exceptionally exclusively serous glands are also encountered (Kallius).

Jacobson's Organ. Mention has been made of the rudimentary structure (**organon vomeronasale**) found in man, almost constantly in the new-born child and frequently in the adult, as a representative of the organ of Jacobson that is present, in varying degrees of perfection, in all amniotic vertebrates (Peter). In many animals possessing in high degree the sense of smell (macrosmatic), the organ is well developed and functions, serving possibly as an accessory and outlying surface by which the first olfactory impressions are received (Seydel).

FIG. 1182.



Portion of frontal section through nasal fossæ of kitten, showing organ of Jacobson. × 20.

In man the organ is represented by a laterally compressed tubular diverticulum, from 1.5–6 mm. in length, that passes backward and slightly upward to end blindly beneath the mucous membrane on each side of the septum. The entrance to the tube is a minute aperture situated near the lower border of the septum, above the anterior nasal spine and the rudimentary vomerine cartilage. The median wall of the diverticulum is clothed with epithelium composed of tall columnar cells resembling those of the olfactory region, but the characteristic olfactory cells are wanting. The epithelium covering of the lateral wall corresponds to that of the respiratory region. In macrosmatic animals branches of the olfactory nerve are traceable to Jacobson's organ in which are found olfactory cells.

PRACTICAL CONSIDERATIONS: THE NASAL CAVITIES.

The nasal cavities have certain important clinical relationships which may be classified as (1) physiological—(*a*) respiratory, phonatory and olfactory; (*b*) sexual; (2) topographical—(*a*) the nasal chamber and the vestibule; (*b*) the premaxillary, maxillary, and palatal portions; (*c*) the septum, and the turbinate bones.

1. (*a*) The air passing out from the pharynx, being confined to the plane of the posterior nares, is not carried up to the olfactory region, so that the odors on the expired breath are not appreciated. When the communication between the respiratory and olfactory portions is cut off, as by swelling of the mucous membrane at the region of union of these portions, loss of smell supervenes. Discharge which may accumulate about the middle turbinate bone or in the upper portion of the vestibule cannot be removed by the act of blowing the nose, for the reason above assigned that the air of expiration cannot pass within the olfactory portion. The act of blowing the nose, or the process of washing out the nose by a current thrown in from the naso-pharynx, will wash out the inferior meatus with ease, provided the discharge is not inspissated, and the parts of the floor of the nose are normal (Allen). An abnormal width or patency of the respiratory portion of the fossa—especially of the inferior meatus—due to imperfect development of the inferior turbinates, has been thought (Lack), by diminishing the *vis a tergo* in blowing the nose and thus favoring the retention and decomposition of the nasal mucus, to contribute to the occurrence of atrophic rhinitis (ozæna). The value of the nose as an accessory organ of phonation consists in its action as a resonating cavity which adds quality, color and individuality to the voice. This function of the nose becomes strikingly

apparent when, as during an acute coryza, the fossæ are more or less completely obstructed and the voice becomes flat and entirely without resonance.

(*b*) The relations between the nasal chambers and the sexual apparatus are of practical importance and have as an anatomical basis the analogy between the mucosa covering much of the turbinates and part of the septum, and the erectile tissue of the penis, and the sympathy between the erectile portions of the generative tract and erectile structures—*e. g.*, the nipple—in other parts of the body.

2. (*a*) The distinction between the nasal chamber and the vestibule is, in the main, based upon the difference in their lining membrane, that of the vestibule being simply a continuation inward of the external integument to the line (*limen nasi*) at which the nasal fossa proper begins. The vestibular cavity is provided with rigid hairs (to aid in arresting foreign particles carried in with the air current), and sebaceous glands, and is especially susceptible to eczematous or furuncular affections. Diseases of the vestibule may, therefore, be dealt with as though they were affections of the skin ; while diseases of the mucosa of the nasal chambers are to be treated on the same principles as those of the mucous membranes generally, with special reference to its erectile character and to its close relation to the underlying periosteum and bone.

(*b*) The sutural lines of the premaxilla, of the maxilla, and of the palatal bones aid in determining the boundaries of the subdivisions of the nasal chamber, which are indicated to some degree by the production of the planes of the sutures of the roof of the mouth, vertically upward through the nasal chambers.

(*c*) The morphological significance of the septum, placed as it is in the median line of the face of the embryo, with the turbinate bones lodged to its right and left sides, remains the same in the skull of the adult, notwithstanding the fact that, with cultivated races at least, the septum is usually deflected through the greater part of its course from the median line. This deflection has been said to be due to the persistent growth of the septal bones in a vertical plane after their edges have united—the apex of the deflection being often found at the junction of the ethmoid and vomer ; any preponderance in strength of one of these bones will cause bending of the weaker—usually the perpendicular plate of the ethmoid. The usual direction of the deflection is to the left, and this has been thought to be due to the habit of using the right hand in blowing the nose. Asymmetry of the nasal chambers is a result of the deflection. One of these chambers, commonly the left, is much smaller than its fellow of the opposite side, and may be occluded, when the right chamber will be larger than normal and possess both osseous and erectile structures which have undergone physiological hypertrophy. Care should be taken to distinguish between such hypertrophy and the effects of diseased action (Allen).

The anterior nares are directed downward and are on a lower plane than the floor of the nose. To examine the interior of the nose the movable nostril must therefore be elevated and the head thrown backward. The speculum shaped for the purpose should not be passed beyond the dilatable cartilaginous portion. With good light one may see the anterior part of the middle turbinate bone, a larger portion of the inferior turbinate, the beginning of the middle meatus, and get a freer view of the inferior meatus, the septum and the floor of the nose. The lower orifice of the nasal duct cannot be seen, although it is only about an inch from the orifice of the nostril, and three-fourths of an inch above the floor of the nose. This is due to the fact that it is concealed behind the attached and depressed anterior end of the inferior turbinate.

To expose better the structures in the external wall of the narrow and rigid nasal fossa, various procedures have been adopted. Rouge made an opening into the anterior nares from the mouth, by incising in the angle between the upper lip and the gum. By separating the alar cartilages from the bones and dividing the cartilaginous septum the movable anterior portion of the nose can be turned upward, giving a full exposure of the nasal fossæ, without leaving an unsightly scar.

To permit a freer exploration with the finger, Kocher divided the septum as far back as possible with scissors. He also divided the roof of the nose near the septum, turning the divided parts aside. An osteoplastic flap may be made by extending this incision upward, dividing the bone in this line and making a second incision around

the alæ and along the side of the nose, again dividing the bone. The flap thus formed can be turned upward, after breaking the bridge of bone between the upper ends of the two incisions, exposing the nasal fossa.

The finger can be passed backward through the nostril far enough to meet the finger of the other hand passed to the posterior nares through the mouth.

The posterior nares can be examined by the rhinoscopic mirror or by the finger introduced through the mouth. Posterior rhinoscopy, like laryngoscopy, is carried out with difficulty, because the region of the naso-pharynx is sensitive and is intolerant of intrusion. In the act of swallowing, the epiglottis protects the larynx by closing the laryngeal opening, and the soft palate rises against the posterior wall of the pharynx, preventing regurgitation into the nose. When the rhinoscopic mirror is used the same thing occurs, so that the view of the larynx and naso-pharynx is shut off. Considerable difficulty is sometimes experienced in training the patient to overcome this tendency. The employment of the nasal douche is based upon the same mechanism. When the stream of fluid passed through one nostril reaches the posterior part of the nose, its progress toward the mouth is obstructed by the elevated soft palate, and it therefore passes around the posterior edge of the septum and back through the opposite nasal fossa.

With the rhinoscopic mirror in good position, and the soft palate quiet, one may see the posterior nares divided by the septum, the turbinated bones, and the meati (especially the middle turbinate and the middle meatus), the roof of the naso-pharynx and the orifices of the Eustachian tubes. The finger introduced through the mouth can feel the same structures, and can recognize naso-pharyngeal adenoids, tumors, or abscesses.

The mucous membrane over the turbinates, owing to the presence of a rich venous plexus, is one of the most vascular in the body, and resembles erectile tissue (page 1968). This and the general vascularity of the nose partly explain the great frequency of epistaxis. The excessive supply of blood to the mucosa may be (*a*) for the purpose of enabling it to raise the temperature and add to the moisture of the inspired air; (*b*) to favor the activity of the numerous mucous glands, the free secretion of which together with the action of the cilia of the epithelial cells is required to remove the dust and the micro-organisms that are filtered from the air during inspiration by the vibrissæ and the cilia themselves; (*c*) to endow it with sufficient vitality to resist the pathogenic action of such micro-organisms. In spite of this defensive quality, the constant exposure to atmospheric irritants often leads to congestions and coryzas, which if long continued and frequently repeated result in hypertrophy of the mucous membrane. This may require removal by cauterization or excision to relieve the consequent obstruction. The mucous membrane is somewhat less closely attached to the septum than to the neighboring parts, and hence hæmatomata of the septal submucosa are not infrequent after an injury to the nose. Such hæmatomata are almost invariably infected and proceed to suppuration forming septal abscesses, the constitutional symptoms (toxæmia) of which may give rise to anxiety if their local cause is overlooked.

Epistaxis is common not only because of (*a*) this vascularity of the mucosa, but also by reason of (*b*) the frequency of trauma to the nose; the relation of its veins (*c*) to the general venous current so that they may be congested in cardiac or in pulmonary disease, or in straining, or in paroxysms of coughing, as in whooping cough; and (*d*) to the intracranial sinuses, so that nose-bleed may be a symptom of cerebral congestion or tumor; (*e*) the bleeding may be vicarious, as in cases of suppressed menstruation (an illustration of the sexual relations of the nasal apparatus); (*f*) it not uncommonly follows ulceration—simple, tuberculous or syphilitic—and in obstinate cases such ulcers should always be sought for.

The source of hemorrhage from the nose is most frequently in the anterior part, particularly on the septum, and is then ordinarily controlled with ease. Usually the patient should be kept upright, with the head back, (not in the usual position leaning over a basin, increasing the tension of the vessels of the neck and head) and should be made to take deep breaths with the arms raised, thus fully expanding the thorax and depleting the cervical veins and, indirectly, the facial and ophthalmic into which the veins of the nose empty. If ordinary means fail, and this is more likely

if the bleeding point is posterior, the posterior nares may be plugged. For this purpose a long silk ligature is passed through the nose to the pharynx and out through the mouth, by means of a Bellocq's cannula or a soft catheter. To the middle of the ligature is attached a plug of gauze slightly larger than the posterior nares, which is then drawn by the anterior end of the ligature into the nasal fossa, which it should tightly fill.

Postnasal adenoids originate in the normally excessive lymphoid tissue—pharyngeal tonsil—of the postnasal space, of which tissue they are a simple hypertrophy. The growth forms a mass in the vault of the naso-pharynx and often extends downward and forward, filling up Rosenmüller's fossæ and involving the orifices of the Eustachian tubes. The tonsils are commonly also enlarged.

The symptoms produced are : (*a*) obstructed nasal respiration, more marked during sleep, when the mouth is closed by the approximation of the tongue to the palate ; (*b*) as a result of this, broken rest and "night terrors" ; and (*c*) as a further consequence (and also from deficient oxygenation), deterioration of the general health, delayed or arrested growth, and anæmia ; (*d*) intermittent partial deafness and recurrent attacks of catarrhal or suppurative otitis media ; (*e*) pigeon-breast from inequality of intra- and extra-thoracic atmospheric pressure.

The early removal of adenoids that produce any or all of these symptoms is usually indicated, and is facilitated by their friability and by the toughness and density of the submucosa on which they lie, circumstances which permit of their usually easy enucleation either with the fingers or with the adenoid forceps and curette.

Naso-pharyngeal growths may be either simple fibromata or fibro-sarcomata. They are usually dense, and contain large venous channels, which have no definite sheath and thus do not retract when severed. Incision into them may therefore be followed by severe hemorrhage with no tendency to spontaneous arrest. Ulceration or abrasion of the surface of these growths is not infrequent, and is also attended by repeated and often dangerous loss of blood.

The nasal fossæ, already very narrow, are frequently further obstructed by pathological conditions, such as deviations of the septum, hypertrophy of the mucous membrane covering the turbinates, spurs on the septum, polypi and tumors. The septum is rarely straight after the seventh year, in about seventy-five per cent. of cases being turned to one or the other side, most frequently the left (*vide supra*). Both the bony and cartilaginous portions, more especially the anterior cartilaginous, are involved. The deflection is sometimes due to a fracture from blows or falls. The whole nose usually deviates more or less to one side. Spurs on the septum commonly occur at the junction of the bony and cartilaginous portions. A deviation of the septum does not necessarily mean that the narrowed nasal fossa is seriously obstructed. It frequently, however, comes in contact with the surface of the turbinates, and may result in an adhesion or synechia from the irritative inflammation which is set up. Operations are often necessary to correct the difficulties arising from deviation of the septum. The concavity on the opposite side will differentiate it from a tumor.

Hypertrophy of the ethmoidal labyrinth, or bulla ethmoidalis, is sometimes so far advanced as to obstruct the nasal fossa on that side. The middle turbinate overlies and yields before this expanded cell, and may even press against the septum to such an extent as to make it bend and obstruct the opposite nasal fossa to a greater or lesser degree. The removal of the middle turbinate is sometimes practiced in these cases (Taylor), or the bulla itself may be obliterated by means of the cutting forceps or curette. Over-development of the bulla ethmoidalis may at times be so great as to occasion obstruction of the upper portion of the corresponding nasal fossa.

The floor of the nose is the widest part, and slopes gradually backward and downward in the upright position, so that collecting mucus tends to run backward and drop into the throat. Rhinoliths, which are incrustations usually about a foreign body, are most frequently found in the inferior meatus, which is the largest. The posterior nares are below the level of the respiratory portion, so that any discharge above the middle turbinate cannot be blown from the nose. The anterior portion of the inferior turbinate slopes downward and forward, and its anterior end is attached

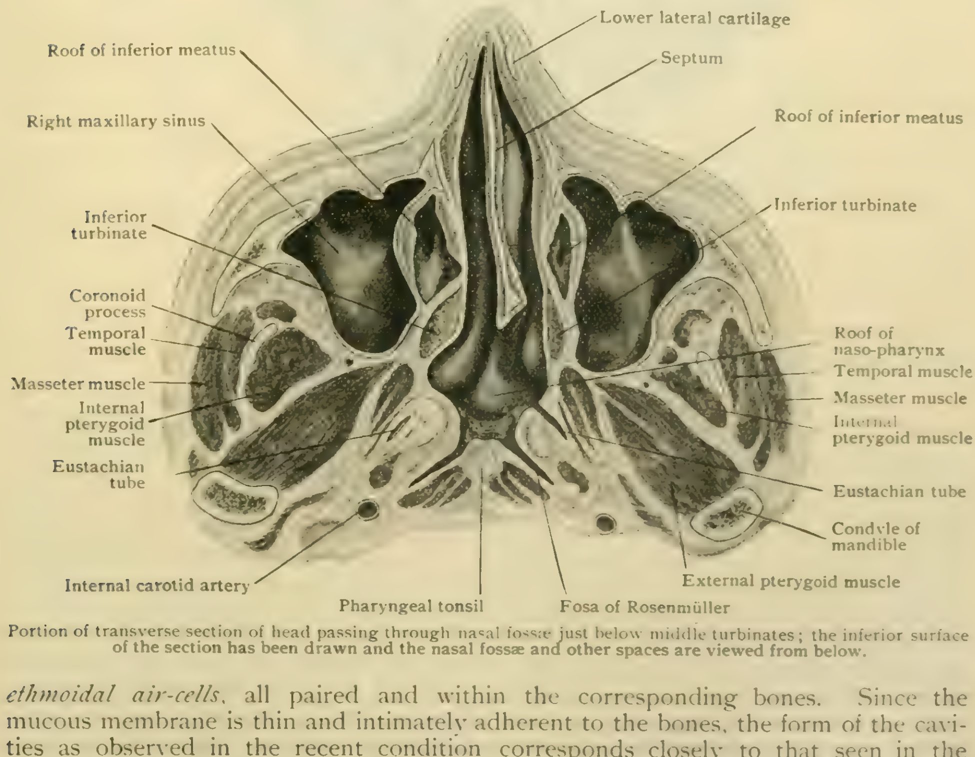
so near the floor of the nose that the roomiest portion of the inferior meatus is posterior. Therefore, the entrance of air into the lower part of the nasal fossa is obstructed, and is favored toward the upper—"respiratory"—portion, especially through the wide anterior opening of the middle meatus, which reaches as high as the tendo-oculi. This anatomical arrangement is the explanation of the fact already mentioned, that odors on expired air are not recognized.

The relations of the nasal chambers explain why a coryza may cause (*a*) lachrymation, by affecting the tear duct, lachrymal sac, and conjunctiva; (*b*) dysphagia, by extending to the pharynx by way of the posterior nares; (*c*) hoarseness or cough, by further extension to the respiratory tract; (*d*) frontal headache, by involving the frontal sinuses; (*e*) "face ache," by implicating the antrum; (*f*) grave intraorbital or intracranial disease, by way of either the ethmoidal cells or the sphenoidal sinuses; basal meningitis by extending along the perineural or perivascular sheaths, or by way of the lymphatics through the cribriform foramina to the floor of the anterior cranial fossa; (*g*) extension to the retropharyngeal lymph node (page 955), into which certain of the nasal lymphatics empty, may result in a retropharyngeal abscess; or (*h*) infection (pyogenic or tuberculous) of the submaxillary, preauricular, or deep cervical nodes may follow nose diseases. The graver of these complications are, of course, associated with the severer infective forms of rhinitis. Malignant growths—commonly sarcomatous—may begin in the nasal chambers and may extend in any of the directions above mentioned.

THE ACCESSORY AIR-SPACES.

The nasal fossæ communicate with a number of remarkable cavities, hollowed out within the surrounding bones, which are filled with air and lined by mucous membrane directly continuous with that of the meatuses. These pneumatic spaces include the *maxillary*, the *frontal*, the *sphenoidal* and the *palatal sinuses* and the

FIG. 1183.



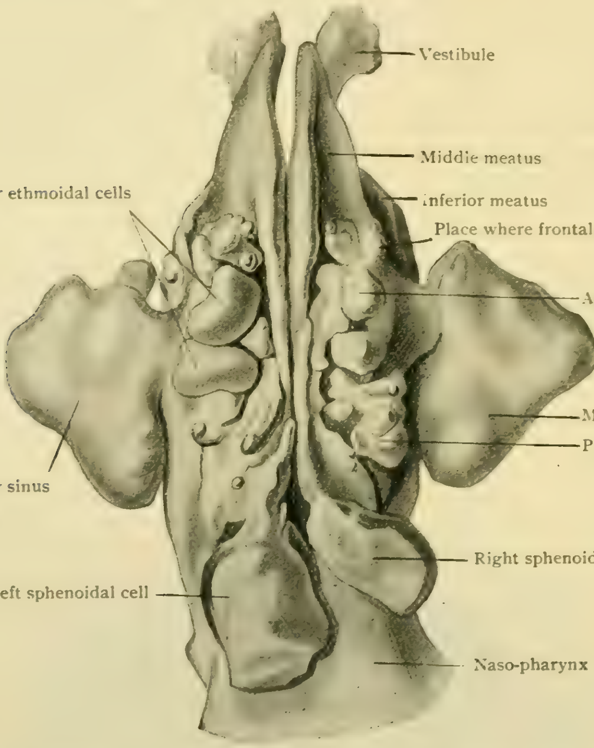
Portion of transverse section of head passing through nasal fossæ just below middle turbinates; the inferior surface of the section has been drawn and the nasal fossæ and other spaces are viewed from below.

ethmoidal air-cells, all paired and within the corresponding bones. Since the mucous membrane is thin and intimately adherent to the bones, the form of the cavities as observed in the recent condition corresponds closely to that seen in the macerated skull. The size and extent of the spaces vary not only at different periods

of life, but also often on the two sides of the same individual; their communications with the nasal fossæ, however, are fairly constant.

The Maxillary Sinus.—This space, (**sinus maxillaris**), or the *antrum of Highmore*, the largest of the pneumatic cavities, lies to the outer side of the nasal fossa and resembles in its general form a three-sided pyramid (Fig. 1184). It occupies the greater part of the superior maxillary bone, so that its walls, with the exception of the postero-inferior one, are very thin and often in places of papery delicacy (Fig. 256). The median wall, or *base*, is directed toward the nasal fossa, from which it is separated by a thin osseous partition in the formation of which the vertical plate of the palate bone, the uncinate process of the ethmoid, the maxillary process of the inferior turbinate and a small part of the lachrymal bone assist. The *apex* lies at the zygomatic process of the maxilla. The *upper* or *orbital* wall is thin and often

FIG. 1184.



Cast of nasal fossæ and accessory air-spaces, viewed from above; casts of frontal sinuses have been removed; natural size. (*Kallius*.)

modelled by the ridge containing the infraorbital canal. The *anterior* wall presents towards the face and is varyingly impressed by the canine fossa. The *postero-inferior* wall is normally the thickest, but is sometimes reduced by extension of the sinus into the adjacent alveolar border. The sinuses are often so modified by local enlargements that the typical pyramidal form is lost and their dimensions materially influenced. As an indication of the size of the average sinus, a sagittal diameter of 35 mm. (1⅜ in.), and a vertical and frontal one of 27 mm. (about 1 in.) each (Kallius), may be taken as approximate measurements. Not infrequently, however, considerable asymmetry exists even to the extent of one antrum being almost twice as large as the other. The usual capacity of the antrum is between 12–18 cc. (3¼–4¾ fl. dr.) with an average of approximately 15 cc., or 4 fl. dr. (Braune and Clasen).

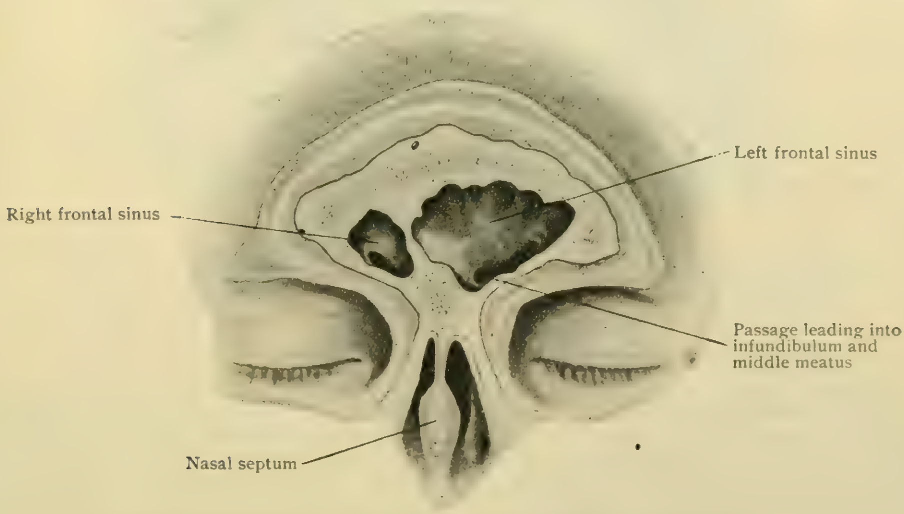
The antrum communicates indirectly with the middle meatus by means of an aperture (**ostium maxillare**) that pierces the upper and anterior part of the base to open into the infundibulum, and thence by way of the hiatus semilunaris, into the

meatus. The ostium, which is usually in the lateral wall of the infundibulum, about one centimeter from the upper end of the hiatus, is an oval or elliptical cleft of variable size, with extremes of length from 3–19 mm. (Zuckerkandl), and from 2–5 mm. in width. An additional communication (**ostium accessorium**), present in about 10 per cent., likewise opens into the infundibulum, lying behind the chief aperture. It is ordinarily small, its diameter being only a few millimeters. The mucous membrane lining the maxillary sinus is directly continuous with that covering the lateral wall of the nasal fossa. With the exception of being thinner, it corresponds in structure with the mucous membrane of the respiratory region, being invested with ciliated columnar epithelium and possessing numerous, although small and scattered, tubo-alveolar glands.

Variations.—The investigations of Zuckerkandl (Kallius) have shown that enlargement of the maxillary sinus may be produced by: (1) hollowing out of the alveolar process (alveolar recess); (2) excavation of the floor of the nasal fossa by extension of the alveolar recess between the plates of the hard palate (palatal recess); (3) encroachment of the sinus into the frontal process of the maxilla; (4) hollowing out of the zygomatic process of the malar bone (malar recess); (5) extension to and appropriation of an air-cell within the orbital process of the palate bone (palatal recess). Contraction of the maxillary sinus, on the other hand, may follow: (1) imperfect absorption of the cancellated bone on the floor of the sinus, or secondary thickening of its walls; (2) encroachment due to approximation of the facial and nasal walls, unusual depression of the canine fossa, excessive bulging of the lateral nasal wall, or imperfectly erupted teeth.

The crescentic projections which quite commonly are seen protruding from the walls into the interior, occasionally are replaced by septa that completely divide the sinus into two cavities, each having its independent opening into the nasal fossa, but not being in communication with each other. These partitions vary in position and direction, sometimes subdividing the antrum into an anterior and a posterior compartment, and at others, into an upper and a lower chamber. In the last case the lower space may communicate with the inferior meatus (Zuckerkandl, Brühl).

FIG. 1185.



Portion of frontal section exposing frontal sinuses which are asymmetrical.

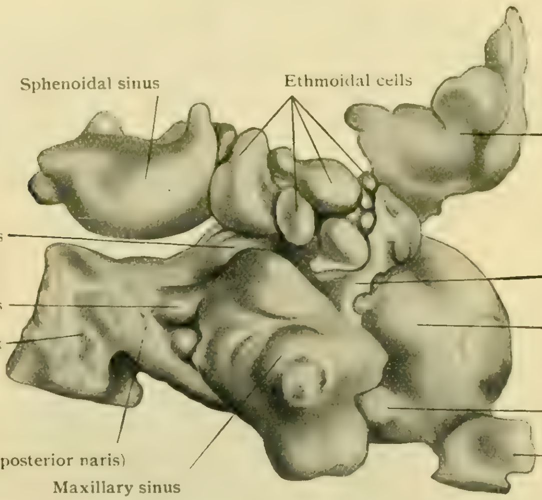
The Frontal Sinus.—The air-spaces between the outer and inner tables of the frontal bones (**sinus frontales**) are very variable in extent and form. The relative development and general position of these cavities are usually indicated by the degree of prominence of the superciliary ridges, but by no means invariably, since numerous exceptions to this correspondence occur. The sinuses are frequently quite asymmetrical (Fig. 1185), one cavity being enlarged, sometimes at the expense of the other, with accompanying displacement of the intervening septum. The latter, usually approximately median in position, is often very thin, but only rarely

incomplete, so that the spaces very seldom communicate. Numerous instances have been observed in which one sinus was entirely wanting. The average dimensions of the frontal sinus, as given by A. L. Turner, include a height of 31 mm. (1¼ in.), a width of 30 mm., and a depth of 17 mm. The capacity varies from 3–8 cc. (Brühl). These spaces are not recognizable in the new-born child, first appearing about the seventh year, after the absorption of the cancellated bone. It is not until after puberty, however, that they attain their full size.. They are usually larger in the male than in the female.

The typical pyramidal form of the space is often modified by the enlargement of the sinus beyond its usual limits, since when exceptionally developed it may extend into the orbital plate of the frontal bone, at times reaching as far as the lesser wing of the sphenoid, or into the median orbital wall, or laterally into the external angular process, or, exceptionally, into the nasal spine beneath the root of the nose. On the other hand, the frontal sinus may be encroached upon by projecting ethmoidal cells.

The frontal sinus communicates with the middle nasal meatus through either the infundibulum, or a passage between the anterior attachment of the middle turbinate and the uncinate process, or both. Its aperture (**ostium frontalis**) lies from 2–10 mm. from the upper end of the hiatus semilunaris. The frontal sinus is lined by a prolongation of the respiratory nasal mucous membrane, diminished in thickness but otherwise of its usual structure.

FIG. 1186.



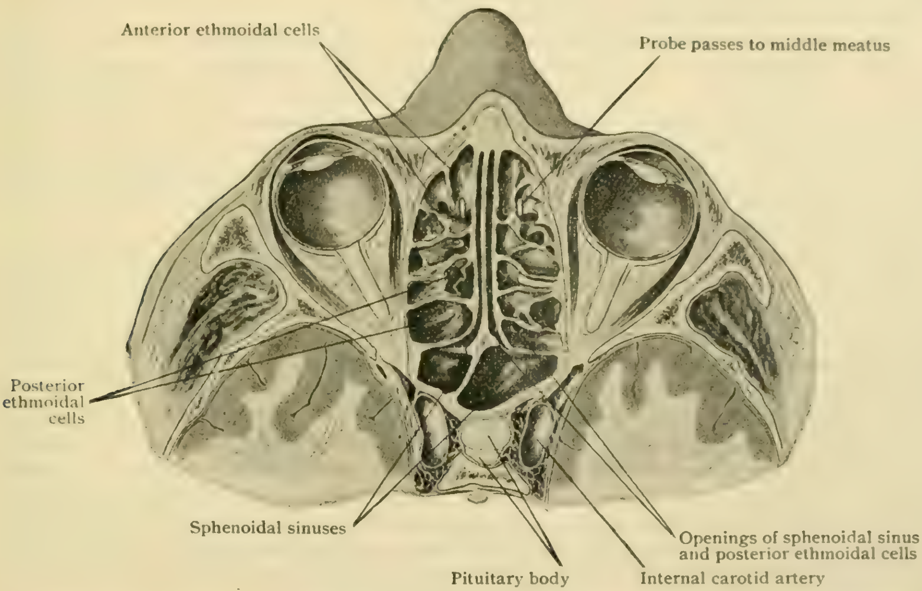
Cast of nasal fossæ and accessory air-spaces, viewed from right side; natural size. (*Kallius.*)

The Ethmoidal Air-Cells.—These spaces (**cellulae ethmoidales**) include a series of pneumatic cavities, very variable in number and size, that from birth lie between the upper part of the nasal fossæ and the orbits, from which they are separated by osseous plates of papery thinness. They are all lined with mucous membrane which covers the thin bony partitions that separate the spaces from one another. When these partitions are deficient, as they often are in old subjects, the intervening septa are entirely membranous. The ethmoidal air-spaces, completed by the articulation of the ethmoid with the frontal, maxillary, lachrymal, sphenoid and palate bones, usually form three groups, the *anterior*, the *middle* and the *posterior cells*. Every space communicates with the nasal fossa, either directly by means of an independent aperture, or indirectly through one or more cells of the same group. Sometimes the cells are so fused that two general cavities, an anterior and a posterior, replace the corresponding groups. When typically arranged, the anterior cells communicate with the middle meatus by means of apertures that open into the upper part of the infundibulum. The *middle cells* also open into the middle meatus,

usually by a crescentric cleft upon or above the ethmoidal bulla, but sometimes into the infundibulum. The *posterior cells* communicate with the superior meatus by one or more openings overhung by the upper concha. Very exceptionally the ethmoidal cells may communicate with the sphenoidal or the maxillary sinuses, or may extend into the substance of the middle turbinate bone. The mucous membrane clothing the ethmoidal cells is exceedingly thin, but corresponds in its general structure, even in possessing glands, with that lining the respiratory region of the adjacent nasal fossæ.

The Sphenoidal Sinus.—The paired air-spaces (sinus sphenoidales) produced by the absorption of the cancellated tissue within the body of the sphenoid bone are separated by an osseous partition and seldom communicate. They are very variable in size and often asymmetrical, with corresponding displacement of the septum. A length of 22 mm., a width of 15 mm., and a height of 12 mm., are the approximate dimensions of the average sinus. The capacity of the latter, as determined by Brühl, is from 1–4 cc. When large, the spaces may appropriate not only a large part of the sphenoid, extending into both wings, the pterygoid processes and the rostrum, but also include the basilar process of the occipital bone. Not infrequently one or

FIG. 1187.



Portion of section of frozen formalin-hardened head, exposing ethmoidal and sphenoidal air-spaces; viewed from above.

more of the posterior ethmoidal air-cells projects or opens into the sphenoidal sinuses. Very exceptionally these spaces may come into close relations with or even open into the maxillary antrum (Zuckerkandl)—a condition normally found in some apes. The sphenoidal sinus of each side communicates with the nasal fossa by means of the spheno-ethmoidal recess, above the superior turbinate and close to the roof of the fossa, by an aperture that pierces the upper part of the anterior wall of the sinus. Through this opening, reduced in the recent condition, the respiratory mucous membrane is prolonged into the sinus which it lines.

The **palatal sinus,** the small air-space within the orbital process of the palate bone, communicates indirectly with the nasal fossa by either the posterior ethmoidal cells or the sphenoidal sinus into which it opens.

Vessels.—Of the *arteries* supplying the nasal fossa the spheno-palatine branch of the internal maxillary is the largest and most important. Entering the nose through the spheno-palatine foramen, it divides into external (posterior nasal) and internal (naso-palatine) branches, which supply an extended tract reaching from the posterior to the anterior nares. The external branches are distributed to the turbinate

bones and the mucous membrane of the meatuses, including the lower part of the olfactory region, and in addition send twigs to the ethmoidal cells and the frontal and maxillary sinuses. The naso-palatine artery supplies the septum and upper part of the olfactory region. Numerous smaller, and for the most part collateral, twigs derived from the anterior and posterior ethmoidal branches of the ophthalmic pass to the upper part of the fossa; from the descending palatine, branches are distributed to the posterior part; and from the lateral nasal and septal, branches from the facial twigs supply the nostril. In addition to those from the posterior nasal, the antrum receives branches from the infraorbital. The sphenoidal sinus is supplied chiefly by the pterygo-palatine artery. The ultimate distribution is effected by capillary net-works which supply the periosteum, the glands and the tunica propria.

The *veins* returning the blood from the rich venous plexuses and the cavernous tissue within the nasal mucous membrane follow three chief paths passing (*a*) forward to the facial vein, (*b*) backward to the spheno-palatine, and (*c*) upward into the ethmoidal veins. The latter communicate with the ophthalmic vein and the veins and superior sagittal sinus within the dura mater. A communication of greater importance, however, is established by a vein that accompanies the anterior ethmoidal artery through the cribriform plate into the anterior central fossa and empties either into the venous plexus of the olfactory tract or into one of the larger veins on the orbital surface of the frontal lobe (Zuckerkandl).

The *lymphatics* within the mucous membrane are represented by an irregular plexus of lymph-vessels in addition to perineural lymph-sheaths surrounding the olfactory nerve-bundles. Both sets may be filled by injection from the subarachnoid space. The larger lymphatics pass backward toward the posterior nares and join two trunks, one of which is continued to the prevertebral node and the other to the hyoid nodes. According to Schieffierdecker, the basal canals (page 951) communicate with the lymphatics and probably facilitate the escape of fluid which aids the glands in keeping moist the epithelium lining the nasal fossæ.

The **nerves** include the special olfactory fibres concerned in the sense of smell, and those of common sensation derived from the ophthalmic and superior maxillary divisions of the trigeminal nerve. The lateral wall of the nasal fossa is supplied from several sources, including the upper posterior nasal branches from Meckel's ganglion and the lower posterior nasal branches from the larger palatine nerve behind, and, in front, the external division of the nasal nerve and the nasal branch of the anterior superior dental, which also distributes twigs to the floor of the fossa. The septum receives its chief supply from the naso-palatine nerve, supplemented by branches from Meckel's ganglion behind and by the internal division of the nasal nerve in front. The mucous membrane lining the antrum receives filaments from the infraorbital nerve by means of its superior dental branches. The frontal sinus is supplied by twigs from the supraorbital and the nasal nerves ; the ethmoidal air-cells by minute branches from the nasal, and the sphenoidal sinus by filaments from the spheno-palatine ganglion.

PRACTICAL CONSIDERATIONS : THE ACCESSORY AIR-SPACES.

Trauma of the accessory sinuses—with the exception of the maxillary antrum, which may be involved in extensive (crushing) fractures of the face—usually takes the form of perforating wounds, commonly from falls on sharp objects. The thinness of their walls, and the ease with which they may be traversed by such a vulnerating body, are well illustrated by a case in which a fall forward on to the tip of an umbrella resulted in a wound which began on the face above the bicuspid teeth, passed through the maxillary sinus, the sphenoidal sinus, and entered the cranium, the ferrule of the umbrella being found embedded in the pons (Treves).

Inflammation of the accessory sinuses is not infrequent, on account of the constant exposure of the nasal mucosa to atmospheric sources of infection. It has a tendency to become chronic because (*a*) the openings of the sinuses are small and—with the exception of the frontal—are badly placed for drainage ; (*b*) the ciliated epithelium, on the activity of which the removal of the sinus contents depends, is apt to be so damaged by the primary inflammation that retention of secretion occurs ; (*c*) the mucosa around the different ostia is so loosely attached that it readily

becomes œdematous and is thrown into folds which later are obstructive; (*d*) foreign bodies (as a carious tooth, in the case of the antrum) have little chance for escape, and mucous cysts, polyps, and lesions of the sinus walls (pyogenic, syphilitic or tuberculous caries or necrosis) are not uncommon; (*e*) one cavity may be infected from another, pus from the frontal sinus entering the ethmoidal cells, or pus from either of these entering the antrum through its normal opening, or through a perforation of its wall in the vicinity of the infundibulum (Lack).

In the greater number of cases, the chief—often the only—symptom of chronic suppuration of the accessory sinuses, is a purulent nasal discharge. Spontaneous recovery is practically impossible, and in the great majority of cases, operation—for disinfection and drainage—becomes necessary. The cavities (as one may act as a reservoir of pus coming from another) may have to be attacked in a definite order. Ordinarily it is possible to determine whether the pus comes from the sinuses that open into the same passage within the middle meatus—the anterior group—or from those which open more posteriorly, above the middle turbinate bone—the posterior group. If no definite evidence can be obtained as to which of the anterior group is involved, it would be well to attack first the antrum, then the ethmoidal cells, and then the frontal sinus. If the posterior group is affected it is usually proper to remove the posterior portion of the middle turbinate and open the posterior ethmoidal cells, later, if necessary, opening the sphenoidal sinus. Occasionally, as in ozæna (on account of the width of the inferior meatus and the atrophy of the inferior and middle turbinates), the opening of the sphenoidal sinus can be seen from the front, and then this sinus may be explored first (Lack).

The **frontal sinuses** do not appear as distinct spaces until about the seventh year, and are developed by a separation of the two tables of the skull, with more or less resulting prominence above the superciliary ridges. There may be a greater relative bulging toward the interior of the cranium, so that the prominence of the superciliary ridges is no indication of the size of the cavities of the sinuses. They are often very irregular in size, one being larger at the expense of the other, the septum deviating to one or the other side accordingly. It is therefore, difficult, at times, to decide which side is involved by disease.

Fracture of the skull over a frontal sinus does not imply that the cranial cavity is opened, even when depression exists. The frequent presence in these fractures of emphysema within the orbit and in the subcutaneous tissue, results from the entrance of air through the communication with the nose, when the latter is blown. The dependent position of its opening into the middle meatus or the infundibulum, provides better drainage for discharges than is the case in the other sinuses, and probably accounts for the relative infrequency of empyema of this sinus, although this advantage is partly offset by the length, narrowness, and tortuosity of the canal, which render it easily liable to obstruction. Swelling of the mucous lining of the outlet of the frontal sinus may thus occlude the canal, and result in abscess (empyema). If this remains undrained the pus would tend to burrow through the weakest point of the wall, which usually leads it through the floor of the cavity into the orbit, giving rise to an orbital cellulitis, and to displacement of the eyeball. It later tends to escape through the inner portion of the upper eyelid. In some cases it extends through the posterior wall of the sinus into the cranial cavity, causing a septic meningitis, or an extradural or brain abscess.

Extensive necrosis of the frontal bone may follow sinus disease, as the frontal diploic vein, which empties into the frontal vein at the supraorbital notch, receives blood from the sinus.

If free drainage is maintained these complications are very rare, but if drainage is defective it is imperative to open the sinus early. This may be done externally, the anterior wall being removed by a chisel or trephine. The incision may be vertical or along the superciliary ridge from the inner end to the supraorbital notch, sometimes dividing the supraorbital vessels. The thinness of the nasal portion of the floor of the sinus is marked—as well as that of the orbital portion—and therefore frontal sinus suppuration is, as a rule, associated with infection of some of the anterior ethmoidal cells, which—surgically—may perhaps be considered as forming a part of that sinus (Lack), although Kümmel notes that he has seen the ethmoidal cells perfectly intact in a series of cases of frontal sinusitis.

Attempts have been made to pass a probe into the ostium frontale from the nose, but this is exceedingly difficult because of the concealed position of its orifice behind the anterior end of the middle turbinate bone, and sometimes because of its tortuous course. Efforts to reach the sinus through the nose are usually made by removing the anterior end of the middle turbinate bone, at the same time opening the anterior ethmoidal cells which are frequently involved by the same inflammatory process. By this method an aperture is left for the permanent discharge of the sinus into the nose, whereas by the external method the opening into the nose may remain closed.

The **maxillary sinus,** or **antrum of Highmore,** is the largest and most important of the accessory sinuses of the nose. It is most frequently the seat of pathological processes, as infections and tumors.

Infection may reach it from the nose through the opening in the middle meatus, when it may be secondary to disease of the frontal and anterior ethmoidal sinuses, the openings into all three being closely associated ; or it may be caused by caries of the teeth, especially of the first and second molars, the roots of which frequently produce prominences in the floor of the antrum, or may very exceptionally extend into its cavity. Occlusion of the small orifice with retention of the pus frequently causes great pain from pressure on the infraorbital nerve in the roof of the antrum. The pus may burrow into the nose, the ethmoidal cells, or the orbit.

The normal orifice is too high on the internal wall for drainage, and is too small for effective irrigation, which may be provided for (*a*), if the cause is a carious tooth, by removing a tooth and making an opening through the roof of the socket into the antrum ; this affords dependent drainage, but permits the entrance of food from the mouth ; (*b*) by perforating the bony wall between the antrum and the inferior meatus with or without removing the anterior end of the inferior turbinate ; or (*c*) by making an opening through the thin anterior wall, above the roof of the second bicuspid tooth, at the level of the canine fossa.

A tumor of the maxillary sinus may be either benign or malignant. Its growth will lead to enlargement of the cavity, and to the following symptoms, one or more of which will predominate, according to the direction it takes : (*a*) *inward*, through the thin inner wall of the sinus, causing epistaxis, obstructed respiration, epiphora from pressure on the nasal duct ; (*b*) *inward* and *backward*, involving the naso-pharynx and interfering with both respiration and deglutition ; (*c*) *forward*, pushing the anterior wall—also thin—before it and obliterating the inframalar depression in the cheek ; (*d*) *upward*, causing infraorbital neuralgia (as the infraorbital nerve runs in the roof of the sinus), toothache from compression of its middle and anterior superior dental branches, face ache from involvement of the other branches of the superior maxillary, and later exophthalmos and diplopia ; (*e*) *downward*, pushing down the arch of the hard palate so that the roof of the mouth on the affected side becomes convex, and, by pressure on the superior dental nerves, causing severe odontalgia in the upper teeth, which later become loosened. Benign growths may be removed through an opening made by cutting away the anterior wall. Malignant growths necessitate excision of the superior maxilla.

In diseases of the **sphenoidal sinuses** their intimate relation with the brain above, the optic nerve and ophthalmic artery above and to the outer side, and, along the outer wall, with the internal carotid artery, the cavernous sinus and the nerves passing through the sphenoidal fissure, should be borne in mind. Such diseases may lead to (*a*) optic neuritis and blindness, if the optic nerve is involved ; (*b*) to general ophthalmoplegia if the third, fourth, the ophthalmic division of the fifth, the sixth, and the sympathetic filaments from the cavernous plexus (all transmitted through the sphenoidal fissure) are implicated ; (*c*) to cavernous sinus thrombosis if the ophthalmic vein—passing through the same fissure—is infected.

Tumors of the pituitary body—resting in the pituitary fossa in the sella turcica and just above the roof of the sinus—may penetrate its cavity. The opening of each sinus is in the upper part of the anterior wall, a very unsuitable position for drainage, in the presence of infection. Encroachment on any of the surrounding structures might lead to serious results. The anterior wall may be exposed and attacked by the surgeon, but only with considerable difficulty, because of its deep situation and its

restricted avenue of approach through the nasal fossa. The chief obstacle is the middle turbinate bone, which must be removed before the orifice can be seen or the anterior wall removed. Any efforts at cleaning pathological tissue from the sinus must be made with due regard for the important structures just outside and the thin intervening bone.

Inflammation of the **ethmoidal cells** is most frequently associated with the presence of myxomatous polypi within the nose. Infection may extend (*a*) upward to the cranial cavity, either directly or by way of the ethmoidal veins, or into the cavernous sinus via the ophthalmic vein, or to the longitudinal sinus—especially in children—by the small vein traversing the foramen caecum; (*b*) outward to the orbit, causing an orbital cellulitis; (*c*) to the lachrymal sac (on account of the contiguity of the lachrymal bone) causing dacryo-cystitis.

A valuable, but not always reliable, sign of involvement of the ethmoidal cells, is localized pain at the inner canthus of the eye (Kümmel), and swelling of the mucous membrane around the middle turbinate may in this—as in infection of the other sinuses—be considered an important symptom. In order to evacuate the diseased cells, the middle turbinate (as in the case of the sphenoidal sinus) must be removed before the ethmoidal cells can be exposed. As, in the large majority of cases at least, the condition is coincident with similar infection of the frontal sinus, the anterior cells may be easily reached from the floor of the latter after it has been opened. The optic nerve, the trochlear nerve, the superior oblique ocular muscle and the anterior and posterior ethmoidal arteries, are the most important structures endangered during this operation.

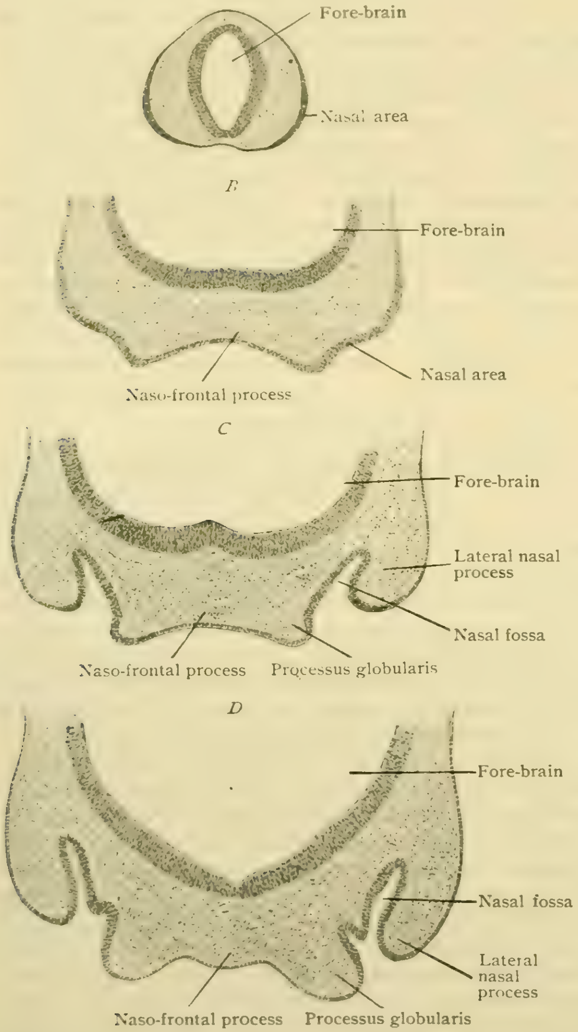
DEVELOPMENT OF THE NOSE.

The earliest trace of the nasal anlage appears about the beginning of the third week of fœtal life as a thickening of the ectoblast to form the *nasal area* at each side of the anterior portion of the head. About one week later the convexly crescentic outline of this area gives place to a slight depression that deepens into the *olfactory pit* or fossa in consequence of the increased thickness of the surrounding mesoblast. The encircling ridge thus produced is best marked on the mesial and lateral boundaries of the fossa (Kallius), where the resulting elevations foreshadow the development of the inner and outer nasal processes. With the forward growth and union of the maxillary process of the first visceral arch with the median nasal process, or processus globularis, to complete the upper boundary of the primitive oral cleft (page 62), the margin of the entrance of the nasal pit becomes closed in below. Subsequently, however, the lateral nasal process extends medially above the maxillary process until it meets the median nasal process and thus becomes the immediate lower and lateral boundary of the opening of the fossa. The latter grows and deepens chiefly upward, towards the brain, and backward and in consequence the olfactory organ for a time consists of two blind pouches, separated by the frontal process, lying above the primitive oral cavity. These pouches invade the mesoblast until their blind posterior ends reach the primitive oral cavity between which and the olfactory diverticula a thin partition, composed of the two abutting layers of epithelium, alone intervenes. This septum, *bucco-nasal membrane* of Hochstetter, becomes attenuated and finally ruptures, the resulting openings, the *primitive choanæ*, establishing communication between the nasal fossæ and the primitive oral cavity. That part of the roof of the latter which extends from the choanæ to the nasal apertures constitutes the *primitive palate*, and contributes not only the anterior portion of the definite palate, but also the tissue forming the lips (Hochstetter). The primitive palate includes contributions from different sources, its middle portion being from the median nasal process and its lateral portions being derived from the lateral nasal process in front and from the maxillary process behind (Peter).

Subsequent to the formation of the primitive palate, about the fifth week, the primitive nasal fossæ increase in size, sink deeper into the head between the median plane and the eye, and come into closer relation with the brain. The nasal fossæ, however, in acquiring their definite expansion additionally appropriate a considerable portion of the primitive oral cavity which becomes separated from the remainder of that space by the formation of the *definite palate*.

The first step in the production of the latter is the appearance, about the ninth week, of the *palatal ridges*, wedge-shaped elevations that grow downward and inward from the maxillary processes. In front these ridges begin at the primitive choanæ, where they are continuous with the primitive palate, and extend backward as far as the tympanic pouches. At first almost sagittal in their plane, the palatal ridges become gradually converted into horizontal plates that come into contact and finally unite along their opposed median edges to complete the roof of the mouth and the floor of the nasal fossæ and the definite or *secondary choanæ*, this fusion being accomplished by the end of the third month.

FIG. 1188.



Frontal sections of fore-brain of rabbit embryos, illustrating early stages in development of nose; in A, nasal area shows as thickening of ectoblast; in B, nasal area is slightly depressed; in C and D, nasal fossæ are forming. × 30.

Coincidently with these changes the primitive choanæ elongate and come to lie on either side of the posterior portion of the nasal septum to which the frontal process has now become reduced. The union of a pair of outgrowths from the palatal plates, beyond their point of fusion beneath the choanæ, produces the uvula, while the remaining ununited portions of the ridges give rise to the palato-pharyngeal arches.

For a time the nasal septum is still incomplete, since it has not yet reached the palate, and the nasal fossæ communicate by means of a cleft between the septum and the palate. With the downward growth of the partition this communication is obliterated, the septum joining the palate along the line of the median suture.

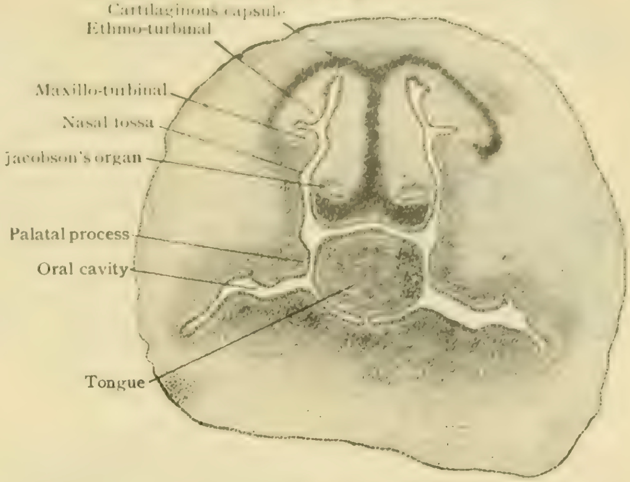
The formation of the anterior part of the floor of the nasal fossæ is more complex since, according to Peter,[1] in this region the palatal processes do not come in contact with each other owing to the interposition of a portion of the partition that separates the primitive choanæ. The palatal plates, however, fuse with this wedge of tissue along the line of apposition except at one point on each side, where the epithelium persists as a solid strand leading downward and inward from the fore part of the floor of the nasal fossa to the roof of the oral cavity. These strands acquire a lumen and become the incisive canals (page 1413) that may persist throughout life and establish communication between the nasal and oral chambers.

The further differentiation of the nasal fossæ of man follows the same fundamental plan that applies to other mammals, but is modified by the reduction that

[1] Anatom. Anzeiger, Bd. xx., 1902.

occurs in the production of the relatively feebly developed human olfactory apparatus. With this differentiation is associated the formation of the turbinates and the intervening clefts (the meatuses) and of the accessory air-spaces. The studies of Zuckerkandl, Killian, Schoenemann, Peter[1] and others have shown that the typical development of the conchæ proceeds from three primary outgrowths from the lateral nasal wall in regions later corresponding to the maxilla, ethmoid and nasal bones. These elevations, appropriately known as the *maxillo-turbinal*, the *ethmo-turbinal* and the *naso-turbinal*, undergo differentiation that leads to the simple or complex definite arrangement of the conchæ found in various animals.

FIG. 1189.

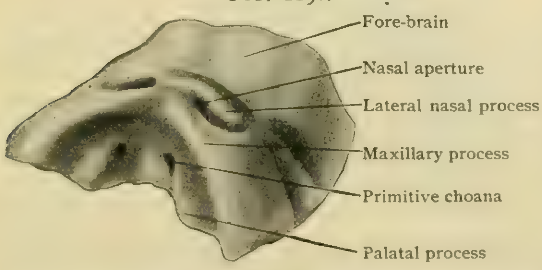


Frontal section through developing nasal fossæ and oral cavity which communicate; palatal processes are forming. × 15.

In man the maxillo-turbinal, later the inferior turbinate, first appears and precedes the ethmo-turbinal plate that later is supplemented by a second scroll, thus producing the middle and superior turbinates respectively. The naso-turbinal, always rudimentary in man, is represented by a small ridge that appears in front of the ethmo-turbinal and above the maxillo-turbinal plates and persists as the agger nasi. The ethmo-turbinal is most intimately related to the true olfactory area and undergoes, even in man, conspicuous subdivision. Although finally reduced to two (the upper and middle turbinates), in the human fœtus, just before birth, five ethmo-turbinal plates defined by six grooves are present (Killian). Persistence in excess of the usual complement accounts for the presence of the supernumerary ethmoidal turbinates so often observed.

As interpreted by Killian, the subsequent modifications of the ethmo-turbinals and the intervening furrows, either by further expansion or by fusion, are not only intimately concerned in producing details modelling the lateral wall of the nasal fossa, as the uncinate process, ethmoidal bulla, hiatus semilunaris and infundibulum, but also associated with the first appearance of the *accessory air-spaces*. The earliest establishment of these spaces precedes the appearance of the cartilage that later encloses them, their relations to the skeleton being, therefore, secondary (Kallius). The ethmoidal air-cells and the sphenoidal sinus are primarily constrictions from the nasal fossæ, while the maxillary and frontal sinuses are more or less direct extensions from the same cavities.

FIG. 1190.



Part of head of fœtus 15 mm. in length, showing primitive choanæ and palate. × 8. (*Peter*)

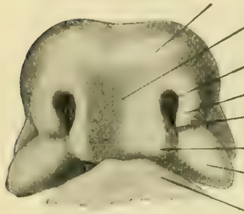
The **maxillary sinus** appears about the middle of the third fœtal month as a minute epithelium-lined sac within the mesoblast at the side of the nasal fossa, from which it has been evaginated; by the sixth month it measures some 5 mm., and at birth has acquired the size of a pea. Until the eruption of the milk teeth provides the

[1] In Hertwig's Handbuch d. Entwikelungslehre, Lief. 4 and 5, 1902.

necessary room for expansion, its growth is retarded. After the sixth year, when the eruption of the permanent teeth begins, the antrum loses its general spherical outline and gradually acquires the definite pyramidal form.

The **frontal sinus** formed as an extension of the nasal fossa during the third fœtal month, is for a time so small that it is usually regarded as absent at birth. Although indistinctly seen during the third year, not until about the seventh is the sinus a definite space; it remains small, however, until puberty, after which its adult proportions are gained.

FIG. 1191.



Anterior end of head of foetus 10.5 mm. in length, showing early development of external nose. × 8. (*Peter.*)

The **sphenoidal sinus,** primarily arises by the constriction and partial isolation of a part of the primitive nasal fossa. Although its development begins during the third fœtal month, the space remains so rudimentary that not until the seventh year has absorption of the cancellous bone progressed sufficiently to make the sinus apparent.

Notwithstanding its rudimentary condition in man, the **organ of Jacobson** develops at a very early period, beginning as a groove-like depression on the median wall of the nasal pit. This groove is converted into a tubular pouch that soon becomes laterally compressed and, by the middle of the third month, measures about .5 mm. in length and receives twigs from the olfactory nerve (Kallius). After the fifth fœtal month the organ suffers regression and becomes rudimentary and variable in comparison with the perfection it attains in animals possessing olfactory sense in a high degree.

The development of the **outer nose** is closely associated with the changes affecting the median and lateral nasal processes—prominences considered in connection with the formation of the upper boundary of the primitive oral cleft (page 62).

Reference to Fig. 1192 shows the median nasal processus, separated by a distinct furrow that soon becomes filled and partially obliterated by ingrowth of young connective tissue, as does likewise the groove between the globular and maxillary processes. At first separated by a relatively wide interval, the *infranasal nasal area* of His, the nasal apertures are brought nearer together by the rapid narrowing of the interposed portion of the frontal process. Eventually the tissue between the globular processes becomes the philtrum of the upper lip and that between the nasal openings persists as the partition between the nostrils. By the end of the second month the external nose is defined, but is very broad and flat and limited above by an arched furrow that separates the convex *nasal margin* (His) from the forehead. The nostrils, originally placed high and for a long time directed forward, gradually descend and assume a horizontal plane as the middle of the arched nasal margin grows downward and forward to become the point of the nose. These changes, however, are not accomplished until near the end of gestation and at birth the bridge of the nose is still small and flat which, in connection with the general breadth of the organ, imparts to the infantile nose its peculiar stumpy appearance. Not until long after birth, and, indeed, not until after puberty, does the outer nose acquire its definite individual form in

FIG. 1192.

Head of fœtus of about 20 days, showing developing nose. × 13. (Rabl.)

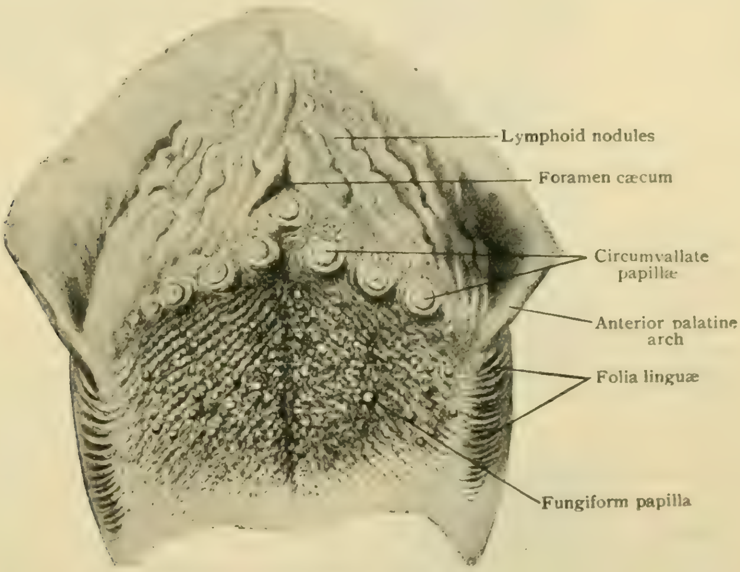
which family and racial characteristics are often so strikingly reproduced. From the second until the sixth month the nostrils are occluded by epithelial plugs which subsequently undergo gradual resolution, so that before birth the nasal apertures are unobstructed. The *cartilages of the outer nose* are derived from the common cartilaginous capsule that constitutes the primary nasal skeleton. Subdivision into the individual plates is probably effected by ingrowth of the surrounding connective tissue (Mihalkovics, Kallius).

THE ORGAN OF TASTE.

In the description of the tongue and its papillæ (page 1575), reference is made to the presence of specialized epithelial structures, the **taste-buds**, that serve for the reception of gustatory stimuli. These bodies collectively constitute the peripheral sense-organ of taste and as such will be here considered.

As implied by their name, the taste-buds (**calyculi gustatorii**) are irregular ellipsoidal or conical bodies, sometimes broadly oval but more often slender in outline, and in the adult measure from .070–.080 mm. in length and about half as much or

FIG. 1193.



Part of dorsum of tongue, showing papillæ.

less in breadth. Since they lie entirely within the epithelium clothing the mucous membrane, the necessary access to the interior of the buds is afforded by minute *pore-canals*, each of which, beginning on the free surface at the *outer taste-pore*, leads through the intervening layer of epithelium to the *inner pore* that caps the subjacent pole of the bud. By means of these canals the sapid substances dissolved in the fluids of the mouth reach and impress the gustatory cells within the taste-buds. Pore-canals are not, however, invariably present, since, as pointed out by Graberg, certain taste-buds remain immature and retain their embryonal form and relations, being broad and conical and in contact with the free surface. In such buds the gustatory cells are few, only two or three, and so superficially placed that a distinct canal is absent. Occasionally double buds are encountered in which two gustatory bodies are implanted by a common base, but partly retain their independence in having separate distal poles, each provided with its separate taste-pore and canal.

The chief position of the taste-buds is within the epithelium lining the sides of the annular groove on the circumvallate papillæ, the buds being more numerous and closely placed on the median than on the lateral wall of the furrow. Their number

has been variously estimated, but it is probable that from 100 to 150 represents the maximum for a single papilla, in many cases the quota being less than one half

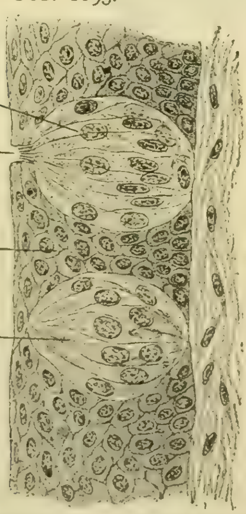
FIG. 1194.

Section of circumvallate papilla from tongue of child. × 70.

of these figures (Graberg). The locality of next importance numerically is the papillæ foliatæ on the sides of the tongue in the furrows of which, even in man, the taste-buds are plentiful.

Additional situations, in which, however, the taste-buds are very sparingly and uncertainly distributed, include the fungiform papillæ, the soft palate, the posterior surface of the epiglottis and the mesial surface of the arytenoid cartilages. Within the fungiform papillæ a few buds may be found on the free surface, where the epithelium is thinnest. Over the soft palate their distribution is irregular and uncertain, while in the larynx the buds are limited to the areas covered by squamous epithelium. According to Davis, between fifty and sixty taste-buds of varying size may be counted on the epiglottis within an area 3 mm. in diameter.

FIG. 1195.



Taste-buds in section; upper one shows gustatory hairs projecting into pore-canal. × 440.

Structure.—Wherever found, the taste-buds consist exclusively of epithelial tissue and, in correspondence with other sense organs, include two chief varieties of elements—the *supporting cells* and the more highly specialized neuro-epithelium, the *gustatory cells*, among which lie the terminal fibrillæ of the nerve of taste.

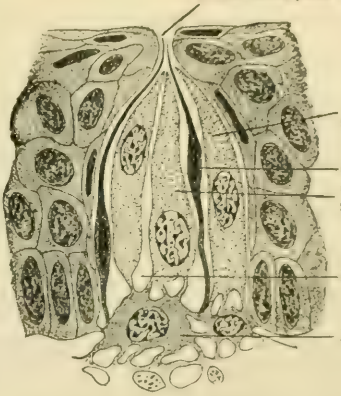
The **supporting cells** are represented principally by elongated epithelial elements that occupy both the superficial and deeper parts of the taste-buds of which they contribute the chief bulk. They vary in their individual contour, being lanceolate, wedge-shaped or columnar, according to the modelling to which they are subjected by the neighboring cells. They possess large, clear, vesicular nuclei that contain little chromatin and, therefore, stain faintly. The position of the nucleus is inconstant, in some cells being near the base and in others in the middle or nearer the apex. The peripheral ends of the

supporting cells, somewhat blunted and flattened and beset with a narrow cuticular zone, are closely grouped to bound the annular opening of the inner taste-pore, through which project the stiff hair-processes of the gustatory cells. Their deeper or central ends are prolonged into one or more protoplasmic processes which unite with similar extensions of the basal cells, as the peculiar supporting cells at the base of the bud are called.

The *basal cells* are modified sustentacular elements, probably epithelial in nature, which occupy the lower fourth of the buds, resting upon the subjacent epithelium and, in turn, affording support for the elongated cells. Although differing in size and details of form, the basal cells are provided with oval nuclei and are generally more or less branched. By means of their protoplasmic processes they are united with the central ends of the longitudinally disposed supporting and gustatory cells, with one another and with the surrounding epithelial cells. The number of basal cells in each bud is small, often only two or three and seldom more than half a dozen being present (Graberg[1], Kallius[2]).

The percipient elements, the **gustatory cells**, are irregularly arranged between the more deeply placed supporting cells and enclosed within a shell formed by the more superficial ones. They are long and fusiform, reaching from the base of the bud to the inner taste-pore, through which the stiff hair-like processes that cap their outer ends project. Their slender nuclei, rich in chromatin and deeply staining, occupy the thickest parts of the cells, which beyond the nucleus are continued in either direction as thin processes. The peripheral ones, as noted, extend not only as far as the inner taste-pore, but through the latter and into the canal by means of the gustatory hairs into which the taste cells are prolonged. The centrally directed ends are usually much the shorter and join the processes of the basal cells. The number of gustatory cells within a single taste-bud varies, in exceptional cases only two or three being present, but more often they are almost as numerous as the supporting cells (Graberg).

FIG. 1196.



Diagrammatic section illustrating architecture of taste-bud. (*Graberg.*)

The capillary clefts observed within and around the taste-buds—the *intra- sub-* and *peri-bulbar* juice-spaces described by Graberg—are regarded by some as existing during life and, therefore, not as artefacts. To these intercellular clefts the last-named authority attributes the function of insuring and facilitating an active lymph-circulation within and around the taste-buds, whereby is effected the prompt removal of foreign substances that might prove deleterious if too long retained in close relation with the delicate sensory elements.

Hermann has shown that the taste-buds are the seat of continual degeneration and repair, sometimes, indeed, entire buds undergoing regression. Whether such destructive processes are to be ascribed directly to the invasion of leucocytes, although the latter are normally found in insignificant numbers within the buds, is still a subject of discussion.

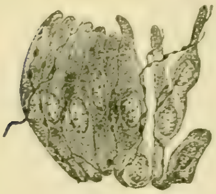
The **nerves** distributed to the gustatory bodies are the fibres of the glossopharyngeal, the nerve of taste. From the rich subepithelial plexus numerous twigs ascend into the epithelium, one set going directly into the taste-buds and the other ending within the surrounding tracts of epithelium. Since the last set—the *inter-bulbar fibres*—probably have no concern with the impressions of taste and serve to convey sensory stimuli of other value, it suffices to note that after repeated division

[1] Anatomische Hefte, Bd. xii., Hf. 2, 1899.
[2] Bardeleben's Handbuch d. Anatomie des Menschen, Lief. 13, 1905.

the ultimate fibrillæ terminate in minute bead-like endings that lie free between the epithelial cells, either near the free surface or at a deeper level.

The nerves distributed to the taste-buds—the *intrabulbar fibres*—enter at the basal pole. Usually numbering from two to five for each bud, on gaining the interior of the latter they undergo rapid division and become numerous. A majority of the resulting fibrillæ ascend in tortuous windings towards the apex of the bud in the vicinity of which some end, while others recurve and end at lower levels. The fibrillæ terminate in free, usually minute knob-like endings, that lie between and often in close contact with the supporting and gustatory cells. It is probable that in no instance do the nerve-fibrillæ actually unite with the gustatory cells, the relation being one of apposition and not of continuity.

FIG. 1197.



Partially separated cells of taste-bud with terminal filaments of gustatory nerve. × 510. (*Arnstein.*)

Development.—The earliest evidences of the taste-buds[1] appear, about the third fœtal month, within the deepest stratum of the immature epithelium as groups of ectoblastic cells that are distinguished by their large size and elongated form from the surrounding epithelial elements. The anlage tends to become conical, the apex gradually reaching the free surface and the base resting or slightly encroaching upon the subjacent connective tissue, from which it is only indistinctly defined. The primary slender form of the developing bud is later replaced by one of broad conical proportions in which the wide base is supported directly by the connective tissue without the interposition of epithelium.

For a time the height of the young taste-bud equals the entire thickness of the epithelium, the position of its apex being marked by a slight depression on the free surface. In consequence of the rapid increase of the surrounding epithelium, this depression gradually deepens until the bud, which meanwhile has grown but slightly, lies at the bottom of a narrow funnel-shaped passage, the pore-canal (Graberg). Previous to the fifth month, the constituents of the taste-bud are apparently of the same character and not until towards the end of gestation is the differentiation between the supporting and gustatory cells clearly established. The definition of the taste-buds from the surrounding tissue is sharpened by the appearance of the so-called *extrabulbar cells*, flattened protecting epithelial elements in which partial cornification probably takes place (Kallius). Coincidently many of the conical embryonal buds gradually assume their more slender and ovoid mature form. Before birth the taste-buds are present not only on the sides but also over the summit of the circumvallate papillæ. While exceptionally some of those in the latter situation may remain, as a rule they disappear and, hence, in the adult the gustatory bodies are usually confined to the sides of the papillæ. Likewise the complement of taste-buds on the fungiform papillæ is much larger at birth than later (Stahr[2]), giving to these papillæ an importance during early childhood that subsequently is lost.

THE EYE.

Although the organ of sight (**organon visus**), strictly regarded, consists only of the eyeball or globe of the eye, it is closely associated with other structures, as the eyelids, the lachrymal apparatus, the orbital fascia and fat and the ocular muscles, which serve for its protection, support and change of axis. The description of some, at least, of these accessory structures therefore appropriately here finds place.

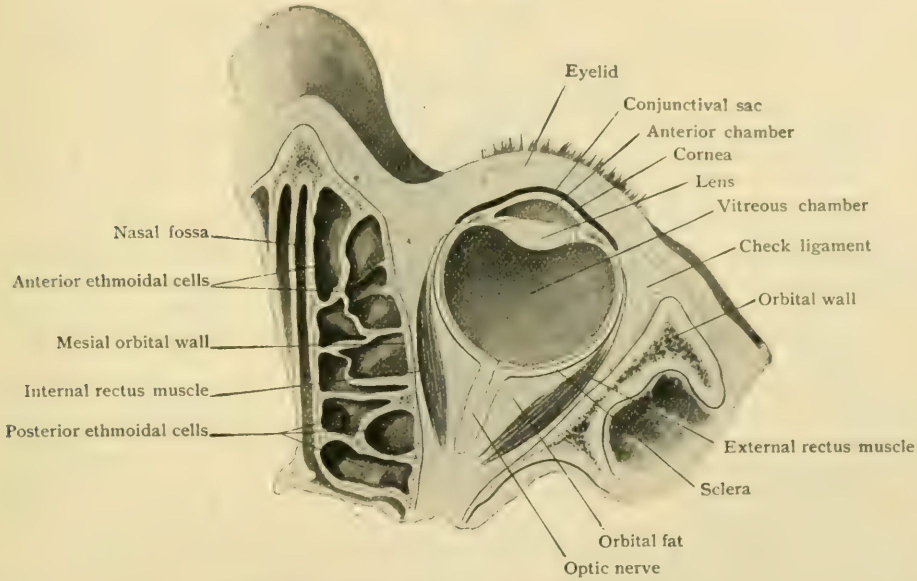
THE ORBIT AND ITS FASCIÆ.

The walls of the orbit have been described in connection with the skull (page 222); suffice it here to point out that in its general form the orbital cavity resembles a pyramid, so modified by the rounding of its angles that it approximates an irregular cone. The *base* corresponds with the orbital opening on the face and the *apex*

[1] Graberg: Schwalbe's Morpholog. Arbeiten, Bd. viii., 1898.
[2] Zeitschr. f. Morphol. u. Anthropol., Bd. 4, 1901.

with the optic foramen. The *median walls* of the two orbits are slightly divergent behind, but almost parallel with the sagittal plane and with each other; the *lateral walls* are obliquely placed and with the sagittal plane form an angle of about 48° and, therefore, with each other one of something more than a right angle. The *axis* of the orbit is directed inward and upward, forming an angle of from 15°–20° with the horizontal plane, and one of about 45° with the orbital axis of the opposite side, which it intersects in the vicinity of the sella turcica. The width of the orbital entrance is about 4 cm. and the height about 5 mm. less, while the depth of the orbit is approximately 4 cm. The space, therefore, is much more capacious than necessary to accomodate the eyeball and the associated muscles, blood-vessels and nerves. The interspaces thus left are occupied by the orbital fat (**corpus adiposum orbitae**), supported by a framework of connective tissue lamellæ prolonged from the orbital fascia which, in turn, is continuous with the periosteum lining the orbit. The latter, also known as the *periorbita*, is thin but resistant and at the various openings in the walls of the orbit continuous with the periosteum covering the adjacent surfaces of the skull.

FIG. 1198.



Horizontal section of right orbit showing eye in position.

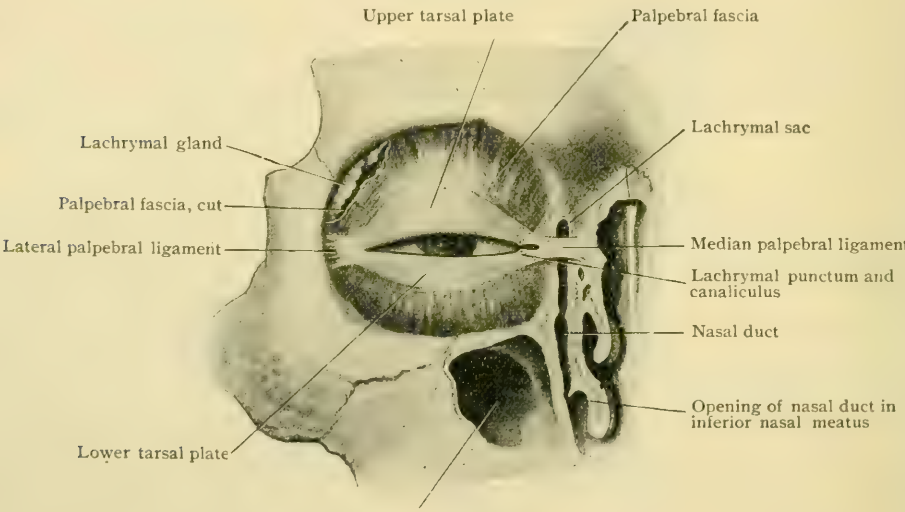
The eyeball does not rest directly in contact with the fatty cushion forming the walls of the cup-shaped recess in which it lies, but is separated from the surrounding adipose tissue by a fascial investment, the **capsule of Tenon** (page 504). This sheet covers the posterior three-fourths of the eyeball and encloses, between it and the eye, the *space of Tenon.* The latter in front begins beneath the conjuctival sac, close to the corneal margin, and behind ends in the vicinity of the optic nerve. It does not, however, quite reach the latter, but terminates where the eyeball is pierced by the posterior ciliary vessels and nerves, thus leaving an irregular oval area uncovered (Merkel). Farther backward the space of Tenon communicates with the subdural lymph-channel prolonged along the optic nerve and thus establishes relations with the intracranial lymph-paths (page 949).

The eye muscles, which together with the elevator of the upper lid have been described (page 502), are invested by fascial sheaths prolonged from the orbital periosteum. These sheaths increase in thickness as they approach the eyeball until, at the points where the tendons of the ocular muscles meet the fascial sheet investing the posterior part of the eye—the capsule of Tenon—the muscle sheaths blend with this capsule on the one hand, and, on the other, are attached at certain points to the orbital wall as robust pointed processes of considerable strength. One such process,

attached to the upper lateral wall, is formed by the fusion of the fascial lamellæ contributed by the sheaths of the levator palpebræ superioris and of the superior and external straight muscles. Another and broader process, inserted along the median wall, includes the blended extensions from the investments of the internal rectus and superior oblique; whilst a third process, formed by the union of prolongations from the fasciæ covering the inferior and internal recti and the inferior oblique, is attached to the lower and median orbital wall. These fascial extensions, passing as they do from the tendons of the eye-muscles to the orbital wall, restrain excessive muscular action and hence the name, *check ligaments*, has been applied, especially to those limiting the action of the internal and external recti. The processes also materially assist in maintaining the position of the eyeball within the orbit. This function is particularly exercised by the robust fascial expansion which stretches across the orbit below the eyeball and as the *suspensory ligament* of Lockwood serves to support the bulbus oculi.

The orbital fat is prevented from projecting forward beyond a certain limit and, therefore, from encroaching unduly upon the eyelid, by a sheet of fibrous tissue, the

FIG. 1199.



Dissection of orbit and adjacent structures, showing palpebral fascia, lachrymal sac and nasal duct.

palpebral fascia or *septum orbitale* (Henle), which stretches across the orbital entrance and materially strengthens and aids the eyelid in closing this aperture. Above, the septum is attached to the border of the orbit, just behind the margin, from which it extends downward to become firmly united with the common fascial investment of the levator palpebræ superioris and superior rectus and, still lower, with the upper convex border of the superior tarsal plate. On each side the septum blends with the corresponding palpebral ligament, while below it passes from the orbital margin to the inferior tarsal plate, after becoming united with the sheath of the inferior rectus. The septum orbitale is not of uniform thickness, but is strongest above, especially towards the sides, and weakest beneath the lower eyelid; further, in a general way, the sheet is more robust near its peripheral bony attachment than where it joins the tarsal plates. In conjunction with the palpebral ligaments, it is so strong behind the angles of the eye that in these localities, particularly medially, it is very unyielding and capable of resisting forward displacement. The internal union of the levator palpebræ superioris with the septum orbitale enables this muscle when it contracts to tense the fascial diaphragm.

Practical Considerations.—The orbital cavity is somewhat pyramidal in shape and its anterior or basal portion is occupied chiefly by the eyeball, which lies slightly nearer the roof and the outer wall than the lower and inner walls. Its diameter

is greatest just back of its anterior margin, which is thickened and offers the best protection to the eye from injury. The upper margin is most marked and with the eyebrow offers a good protection to the eye in that direction. The inner margin is not prominent, but is well reinforced by the bridge of the nose. The outer edge is least prominent, and on that side palpation is possible as far back as the equator of the globe. For this reason, and because the outer walls converge backward while the inner walls are parallel, incisions for reaching the interior of the orbit are best made on the outer side. The walls are thin and easily fractured by direct violence, as from canes and similar objects, which sometimes enter the adjacent cavities, as the ethmoidal. Tumors may encroach upon the orbital space either by causing the absorption of the thin intervening bone, or by growing through one or more of the openings in its wall, as through the optic foramen and sphenoidal fissure from the cranial cavity, the nasal duct from the nose, or the spheno-maxillary fissure from the temporal or zygomatic fossæ.

The eyeball occupies about one-fifth of the orbital cavity, the remaining space being filled by nerves, vessels, muscles, the lachrymal gland, fat, and a system of fasciæ. In the ordinary case a straight edge placed against the upper and lower margins of the orbit will just touch the closed lids covering the apex of the cornea, but will not compress the eye. A straight line between the two lateral margins would pass back of the cornea, on the outer side posterior to the ora serrata and on the inner side at the junction of the ciliary body and iris.

An *exophthalmos* is a protrusion forward of the ball, and is usually due to pressure from behind, more rarely to paralysis of the recti muscles. Some of the more common causes of retrobulbar pressure are orbital cellulitis or abscess, tumors, distension of the orbital vessels, and excess of fat.

Enophthalmos, due to exhausting disease, is more apparent than real, but a true sinking of the globe may be due to paralysis of Müller's muscle due to lesion of the sympathetic, to atrophy of the retro-bulbar cellular tissue caused by trophic disturbance, to fracture and depression of the orbital bones with cicatricial adhesion and contraction, and to injury of Tenon's capsule and the check ligaments.

Inflammation of the capsule, or *Tenonitis*, may be due to constitutional poison or to infection following operations involving it, as in tenotomy of the ocular muscles. It may be an extension from an inflammation of the eyeball. The inflammatory exudate in the capsule and adjacent tissues will sometimes cause a slight exophthalmos, and the eye will be immobile. All the extrinsic muscles of the eye pierce the capsule about the equator of the globe to reach their insertions in it. Each muscle receives a tubular investment from the capsule, which fuses with the proper sheath of the muscle and leaves a small bursa on the anterior surface of each. To open the capsule for a tenotomy, the incision is made just back of the cornea, and goes through only the conjunctiva and outer layer of the capsule. The desired tendon is easily found and brought out with a hook, when it is divided. The capsular prolongation about the tendon prevents retraction of the stump after the division, and so preserves the function of the muscle. This is aided by expansions of the capsule passing to the margins of the orbit and continuous with the periosteum. Those passing from the internal and external recti are stronger than the others and are called the *internal* and *external check ligaments*. They are united by a layer of fascia (suspensory ligament of the eyeball) passing under the eyeball so that the eye is supported after the bony floor of the orbit has been removed, as after excision of the superior maxillary bone. If the outer layer of the globe is left after enucleation of the eye, the muscles will still have an attachment and be capable of moving an artificial eye fitted to the stump.

While the movements of the eyeball are free in all directions, as in a ball and socket joint, no change in position of the eyeball, as a whole, takes place, as the centre of rotation is about in the centre of the globe. By these movements the image of the object to be especially seen is fixed upon the most sensitive part of the retina.

The internal rectus draws the ball directly inward and the external rectus directly outward. The other four muscles, the superior and inferior recti and the two oblique, have a complicated action. The upward and downward movements

are controlled chiefly by the superior and inferior recti respectively, but each has a slight adducting and a slight rotating movement—*i.e.*, the superior rectus will move the upper extremity of the vertical meridian slightly inward (intorsion), and the inferior rectus will move the same part slightly outward (extorsion). The superior oblique is attached to the globe behind the equator, and lower than its pulley, so that in addition to its chief or internal rotating action upon the upper limit of the ball it has also an elevating effect upon the posterior portion, the cornea moving downward. Since its pull is inward, the cornea also moves inward. The chief movement of the inferior oblique is rotary in the opposite direction (extorsion of the upper part). It is likewise inserted into the posterior half of the globe, which is depressed by it, and the cornea is raised and moved outward. In elevation of the cornea by the superior rectus the internal rotation of this muscle is counteracted by the inferior oblique, and in a similar manner when the cornea is moved downward by the inferior rectus, its external rotation is opposed by the superior oblique. The upward and outward movement is produced chiefly by the superior and external recti, the inferior oblique opposing the intorsion of the superior rectus. Motion downward and outward is due to the external and inferior recti, the superior oblique opposing the outward wheel action of the inferior rectus. The downward and inward motion is due to the internal and inferior recti, the superior oblique opposing the inferior rectus.

When one muscle is weaker or larger than its opposing muscle, the eye is turned to the side of the stronger, producing *strabismus* or *squint*. It is usually turned laterally, most frequently to the inner side producing internal or convergent strabismus. All the recti except the external are supplied by the oculomotor nerve. If that nerve is paralyzed only the external rectus can act, and an external squint will result. If the sixth cranial nerve (abducens) which supplies the external rectus is paralyzed, the eye will turn inward, the superior and inferior recti opposing each other.

Paralysis of one or more muscles may occur. If a single muscle is involved it is usually the superior oblique or external rectus, as each of these is supplied by a separate cranial nerve, the fourth and sixth respectively.

Although the *third* or *oculomotor* has a much wider distribution than these, supplying all the other extrinsic muscles, as well as the ciliary muscle and sphincter of the iris, when it is completely paralyzed the clinical picture is definite. Ptosis is present and is due to paralysis of the levator palpebræ. External strabismus and slight depression of the eye are produced by the unopposed action of the external rectus and superior oblique, while the eye is otherwise motionless. The pupil is dilated from paralysis of the sphincter of the iris, and accommodation for near objects is lost from paralysis of the ciliary muscle. Slight exophthalmos appears from paralysis of all but one of the recti muscles.

The *fourth nerve* alone is rarely paralyzed. There will be little disturbance of function, since the motion of the superior oblique is performed partly by the other muscles. The eye will turn inward when the object looked at is lowered, and upward only when the object is turned far toward the healthy side. One eye must be closed to prevent double vision or diplopia.

Of the single paralyses, that of the *sixth nerve* is most frequent on account of its extended course from its origin in the brain to its peripheral termination in the external rectus, rendering it liable to involvement by adjacent pathological processes, as meningitis, tumors, or hemorrhages. Such lesions may involve it alone, or together with a series of cerebral nerves, paralyzed one after another from a progressing pathological condition, which would then probably be at their central origin, or in the wall of the cavernous sinus, where they are close together. The sixth nerve may be paralyzed by a fracture of the base of the cranium in the middle fossa.

When the *ophthalmic division* of the *fifth nerve* is paralyzed, there follows anesthesia of the conjunctiva of the globe and upper lid, and of the other parts supplied by this nerve. The lids do not respond reflexly, as usual, for protection of the cornea, which is liable then to troublesome ulceration.

The *cervical sympathetic* supplies the dilatator muscle of the iris, and reaches the cranium along the internal carotid artery. When the cervical sympathetic is paralyzed

the pupil contracts. There will be some drooping of the upper lid due to paralysis of the superior palpebral muscle of Müller which passes from the under surface of the levator palpebræ muscle to the upper margin of the upper tarsal cartilage, and is supplied by the cervical sympathetic. There will be slight enophthalmos from paralysis of a thin layer of unstriped muscle passing across the spheno-maxillary fissure (orbitalis muscle of Müller).

The normal pupil will contract for accommodation and convergence to near objects and from stimulation by a bright light. An Argyll-Robertson pupil is one which does not react, either directly or indirectly (consensually) to the influence of light, but contracts promptly on convergence of the visual axes. The exact situation of the lesion is uncertain; it may involve the fibres which pass from the proximal end of the optic nerve to the oculomotor nuclei; it may be nuclear in its position; or it may be in the spinal end of the floor of the fourth ventricle.

Owing to the relatively large amount of fat and loose connective tissue in the orbit, infection may lead to an extensive *orbital abscess*, so that an early opening is imperative to prevent disturbance or loss of sight. The muscles may be impaired by the process, leading to the lessened mobility of the eye. The optic nerve may be inflamed with resulting atrophy and permanent impairment of sight, and the other ocular nerves may also be paralyzed. From the exophthalmos the optic nerve may be stretched, although the degree of stretching permitted without disturbing sight is often remarkable. Pus may enter the cranial cavity through the optic foramen, and set up a meningitis or a brain abscess.

Injuries of the orbital tissues are usually the result of penetration by foreign bodies. The eye has been pried out by the finger, or thumb, on the outer side by insane people, or in fights, the finger being readily forced back of the equator of the globe. There are cases in which the eye has been replaced and vision regained after such accidents, although it is usually lost.

Fracture of the bony wall of the orbit ordinarily leads to hemorrhage into the soft tissues, showing later under the conjunctiva of the ball (subconjunctival ecchymosis). If the neighboring air cavities, as the ethmoidal and sphenoidal sinuses, are involved, emphysema of the orbit may result. The exophthalmos from air behind the eye, can be reduced by backward pressure, the air being forced back into the air sinuses. A collection of blood would not disappear by such pressure. In cases of emphysema the patient should be instructed not to blow the nose, as by that act additional air is forced into the orbit.

Tumors of the orbit are comparatively common. They may begin in the adjacent cavities and invade the orbit secondarily. The most important symptom in all cases is exophthalmos. Pain and paralysis from pressure on the nerves, and congestion and edema of the lids from pressure on the veins frequently occur.

THE EYELIDS AND CONJUNCTIVA.

The **eyelids** (**palpebrae**) are two movable folds of integument—an upper and a lower—strengthened along their free margins by a lamina of dense fibrous tissue, the *tarsal plate*, and modified on their deeper aspect so that this surface resembles a mucous membrane, the *conjunctiva*. When in apposition or closed they completely cover the orbital entrance and the eyeball; at other times, when open, they cover the periphery of the orbit but allow a variable portion of the anterior part of the eye to remain exposed.

The **palpebral fissure** (**rima palpebrarum**) is bounded, above and below, by the free margins of the lids and at the ends, where the lids join, by two fibrous bands, the median and lateral **palpebral ligaments.** Of these the inner and stouter springs from the nasal process of the superior maxillary bone and the narrow outer one is attached to the malar bone. The palpebral fissure is an oval cleft of not quite symmetrical form, since the curvature of its upper boundary is somewhat greater than that of the lower; further, the points marking the summit of the two curves neither correspond to the middle of the arches nor lie opposite each other, that of the upper arch lying nearer the mid-line and that of the lower nearer the lateral wall. Neither is the palpebral fissure strictly horizontal, since the inner

of its ends, the *angles* or *canthi*, lies slightly (from 4–6 mm.) lower than the other one. The free borders of the lids meet at the outer canthus without change of curvature, but on approaching the inner canthus they alter their direction and extend medially for several millimeters before meeting. In this manner immediately external to the inner canthus the lids bound a shallow ⊃-shaped recess, about 5 mm. long, known as the **lachrymal lake** (**lacus lacrimalis**).

FIG. 1200.

Three views of living eye, showing relations of eyeball to palpebral fissure and details of inner canthus.

The palpebral fissure, which possesses an average length of 30 mm. and a height of from 12–14 mm., is subject to considerable individual variation in size, thereby exposing a variable amount of the eyeball. In consequence, the appearance of a larger or smaller eye is produced, an impression, however, that depends upon the size of the opening between the lids and not upon differences in the eyeball itself, the diameters of which, under normal conditions, are practically constant. The height of the palpebral fissure in young children is relatively greater than in the adult, a peculiarity that confers the characteristic wide-eyed appearance in early life.

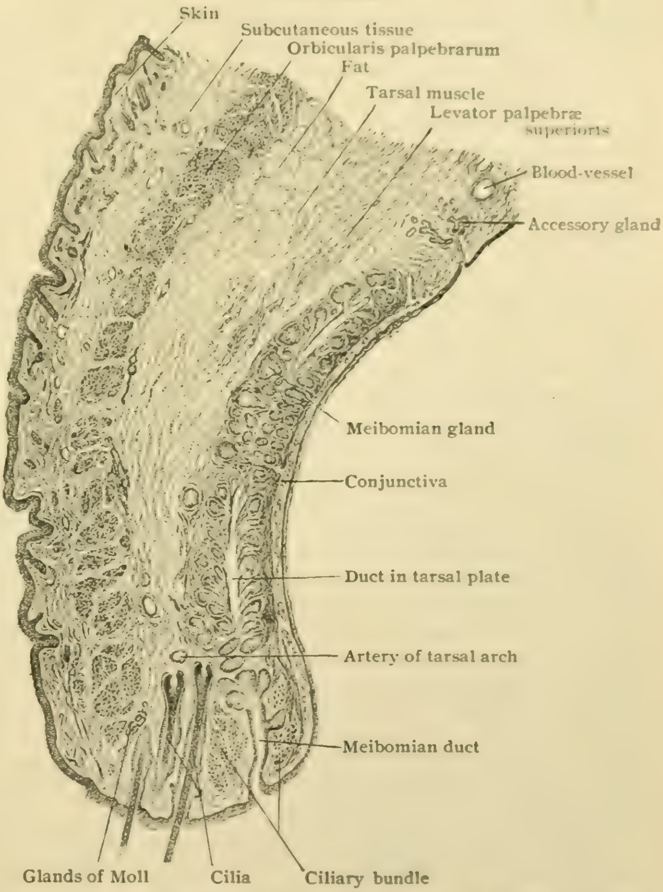
The upper lid is not only much the broader, its height being about double that of the lower one, but also the more movable and the chief agent in closing the palpebral opening. When the latter is closed the free edges of the two lids are in contact throughout their length, the anterior margin of the upper one overlapping slightly the corresponding edge of the lower. The line of apposition is somewhat arched, with the convexity directed downward, and falls below a horizontal line passing through the inner canthus. When the eyelids are separated to the usual extent, the free edge of the upper lid lies just below the upper margin of the cornea, a narrow crescentic area of which it masks, while the corresponding border of the lower lid falls slightly below the inferior corneal margin. The position of the pupil is about midway between the two canthi. When the eyelids are closed, the upper fold covers the entire cornea, its lower border lying opposite the corresponding margin of the cornea.

Viewed in sagittal section (Fig. 1201), the free border of the lid presents a well-defined posterior margin, along which open the minute ducts of the *tarsal glands*, whilst the anterior margin is rounded and passes insensibly into the adjoining external skin-surface and is beset with the eyelashes. The latter, the **cilia**, are stiff outwardly curving hairs, which number from 100–150 in the upper lid and about half as many in the lower. With the exception of about 5 mm. next the inner angle, where the lids border the lachrymal lake and the eyelashes are absent, the cilia are arranged in a double or triple row, with the longest (8–12 mm.) in the centre of the upper series, Although their follicles occupy a zone of from 1–2 mm. in width, the free ends of the cilia lie practically in a single row, the longer and more closely set upper lashes either crossing or overlying the shorter ones of the lower lid.

The palpebral fissure leads into the **conjunctival sac**, which, when the lids are in contact, is a closed capillary space between the lids and the anterior surface of the eyeball. When the cleft is open, the conjunctival space becomes an annular groove of unequal depth, its height being from 22–25 mm. behind the upper lid and only about half as much behind the lower, and being shallowest at the inner angle. That part of the sac which covers the posterior surface of the lids constitutes the **palpebral conjunctiva** and that reflected onto the eye ball is the **bulbar conjunctiva,** while the bottom of the groove, where these two portions are continuous, is known as the **fornix conjunctivæ,** the superior and inferior being distinguished.

The **lachrymal lake** (**lacus lacrimalis**) is the shallow bay into which the conjunctival sac is prolonged for about 5 mm. between the medial ends of the eyelids. It contains an irregularly oval or comet-shaped elevation, the **lachrymal caruncle.** The latter (**caruncula lacrimalis**) consists of an islet of modified skin from which project usually about a dozen minute and scarcely visible hairs, provided with large sebaceous and smaller sweat glands and embedded in a cushion of fatty tissue. Just to the outer side of the caruncle, a vertical crescentic fold, the **plica semilunaris,** indicates the limit of the bulbar conjunctiva. The fold is of interest as probably representing in a very rudimentary way the nictitating membrane, or third eyelid, of the lower animals. The semilunar fold frequently contains a minute plate of hyaline cartilage as the vestige of the stronger bar in the nictitating membrane. Likewise the small group of alveoli sometimes found within the base of the fold is regarded as the homologue of the Harderian gland of the lower types. The points at which the slightly curved boundaries of the lachrymal lake pass into the more arched edges of the eyelids are emphasized by little elevations, the **lachrymal papillæ,** each of which is pierced by a minute aperature, the **punctum lacrimalis,** that marks the beginning of the canals by which the tears are normally carried off from the conjunctival sac.

FIG. 1201.



Vertical section of upper eyelid of child. × 15.

Structure of the Eyelids.—The eyelid comprises five layers which, from without inward, are: (1) the *skin*, (2) the *subcutaneous tissue*, (3) the *muscular layer*, (4) the *tarso-fascial layer* and (5) the *conjunctiva.*

The *skin* covering the outer surface of the eyelids is distinguished by its unusual delicacy, being thin and beset with very fine downy and widely scattered hairs, provided with sebaceous follicles; small sweat glands also occur. It presents numerous

ineffaceable transverse creases which, with advancing years, are supplemented by vertical furrows. Towards the inner canthus, particularly in the lower lid, pigment exists in variable quantity, often in amount sufficient to confer a distinct brownish hue to the integment.

The *subcutaneous tissue* is distinguished by the entire absence of fat, its loose texture and great extersibility and elasticity. In consequence of these properties, it sometimes becomes the seat of extensive swelling after edema or hemorrhage.

The *muscular layer*, for the most part consisting of the annular bundles of the *orbicularis palpebrarum*, is in fact so blended with the subcutaneous tissue as to be practically embedded within the latter. Reference to the description of the orbicularis palpebrarum (page 484) will recall the general division of the muscle into an orbital and a palpebral portion, and the relations of the deeper or lachrymal slip (*tensor tarsi*) to the tear-sac and the tarsal plate. In vertical sections of the eyelid (Fig. 1201) the circularly arranged bundles of the palpebral portion show as transversely cut groups of muscle-fibres enclosed by condensations of the surrounding areolar tissue. A distinct annular tract, known as the *ciliary bundle* (*m. ciliaris Riolani*) lies close to the free border of the lid, chiefly between the tarsal plate and the hair follicles, but in part often also between the conjunctiva and the tarsus. In the upper lid, in addition to the circular bundles of the orbicularis palpebrarum, the terminal strands of the longitudinal fibres from the levator palpebræ superioris descend along the deeper surface of the first-named muscle. Some of these penetrate between the circular bundles and end in the deeper layer of the skin; others descend more vertically to find their insertion in the upper border of the tarsal plate.

Under the name, *tarsal muscles* or *muscles of Müller*, are described the uncertain bundles of involuntary muscle that are found in the vicinity of the convex border of the tarsi. Those within the upper lid arise from the tendon and intermingle with the fibres of the levator palpebræ, with the course of which they agree, and end either by insertion into the upper border of the tarsal plate, or into the adjacent fibrous tissue. In the lower lid, they are less numerous and regular, and extend from the fornix conjunctivæ to the adjacent border of the tarsus. The *tarso-fascial layer* is represented next the margins of the lids by the tarsal plates and beyond the latter by the septum orbitale.

The **tarsal plates** (tarsi) are two lamellæ of dense fibrous tissue, one in each lid, that occupy the margins of the eyelids, to the maintenance of whose form they largely contribute. They are crescentic in outline, the borders next the lid-cleft being only slightly curved and almost straight and the thinner distal borders markedly convex. Their ends are joined to the palpebral ligaments which branch into upper and lower limbs for the attachment of the tarsal plates. The upper tarsus is the more arched and broader, measuring about 10 mm. or about double the lower plate, in both cases the median ends of the crescents being blunted and less pointed than the lateral. The plates are approximately 1 mm. in thickness and consist of densely felted fibrous tissue, and are blended in front and below with the subcutaneous tissue, above with the septum orbitale and the insertion of the lid-muscles, and behind with the conjunctiva.

In addition to preserving the curvature of the lids, the tarsal plates lodge the linear series of the **Meibomian** or **tarsal glands** (glandulae tarsales). These structures, between thirty and forty in number in the upper lid and about one-third less in the lower one, consist of a chief tubular duct, placed vertically and lined by stratified squamous epithelium, which is beset with numerous simple or branched, irregular, flask-shaped alveoli. The latter contain cuboidal epithelial elements that resemble in appearance and condition those found in sebaceous follicles, to which class, in fact, the tarsal glands belong. They secrete an oily substance, *sebum palpebrarum*, which is discharged through the minute punctiform orifices of the ducts that, on everting the edges of the lids, are seen as a row of dark points just external to the sharp conjunctival border of the eyelid. In this manner the latter is kept lubricated, and thus, under usual conditions, maintains an effective barrier against the overflow of the tears from the conjunctival sac. Within the free edge of the eyelids, just in advance of the tarsal plates, lie the **glands of Moll,** and the **glands of Zeiss.** The former

are coiled tubules, resembling modified sweat glands, the latter sebaceous glands, the ducts of which usually open close to or into the mouths of the follicles of the eye-lashes.

The **palpebral conjunctiva** lines the ocular surface of the eyelids. Since the latter are developed as integumentary folds, at first the conjunctiva resembles the skin, but after the temporary closure of the lids, from the middle of the third month until shortly before birth, it loses its original character, and later, bathed continuously with the secretion of the tear-gland, assumes the translucently rosy tint and general appearance of a mucous membrane, as which the conjunctiva is often regarded. Over the tarsi the palpebral conjunctiva is so tightly adherent to the underlying fibrous plate, that the tunica propria is reduced to an insignificant layer and the Meibomian glands shimmer through the smooth translucent conjunctiva and appear as parallel yellowish stripes. On gaining the *retrotarsal fossa*, along the convex border of the tarsal plates, the conjunctiva becomes loose and movable and marked by circular folds since the tunica propria, which here connects the epithelium with the underlying fascial tissue, is plentiful. Small tubules, the **glands of Henle,** often occupy the sub-epithelial tissue of this part of the conjunctiva. In the fornix and its vicinity minute *lymph-nodules* occur normally, either discrete or in small groups. In the same locality and at the convex borders of the tarsi, small nests of tubular alveoli, known as *accessory tear-glands*, or *glands of Krause*, are found, being much more numerous in the upper than in the lower lid.

The **bulbar conjunctiva** passes from the fornix onto the anterior part of the eyeball, over which it extends, unwrinkled but gradually thinning, as far as the corneal margin, at which point (*limbus corneæ*) the tunica propria ends and the epithelium alone continues uninterruptedly over the cornea. During its passage from the free edge of the eyelid to the cornea, the character of the conjunctival epithelium varies in different parts of the sac. Thus, at the border of the lids and for a few millimeters over the tarsi, it resembles the epidermis in being stratified squamous. Towards the convex border of the tarsal plates the squamous type gives way to the cylindrical ; in the retrotarsal fossa, throughout the fornix and for a short distance (.5–1 mm.) over the eyeball, the epithelium is exclusively columnar, varying in thickness and in the number of its layers ; whilst over the cornea and adjacent parts of the sclera, the epithelium is again stratified squamous.

Vessels of the Eyelids.—The *arteries* chiefly supplying the eyelids are the superior and inferior palpebral branches from the ophthalmic and from the lachrymal arteries. These form the first source, the internal palpebral, which arise either separately, or by a short common stem, pierce the septum orbitale a short distance above or immediately below the internal palpebral ligament, and, in addition to sending twigs to the lachrymal caruncle, canals and sac, pursue a tortuous course near the free margin of the lids towards the external canthus. On nearing the latter the superior and inferior internal branches join the corresponding branches from the external palpebral and from the lachrymal, as well as anatomosing with twigs from the superficial temporal and transverse facial arteries. In this manner a *tarsal arch* is formed in each lid along the base of each tarsus, between the latter and the orbicularis muscle, from which perforating twigs penetrate the tarsal plates for the supply of the Meibomian glands and the adjacent conjunctiva. In the upper lid a less regular *secondary tarsal arch* is formed along the convex border of the tarsus by the anastomosis of the palpebrals and the frontal and supraorbital branches. A similar, but less constant and complete, arch occurs in the lower lid.

In consequence of the double path of escape of the blood from the orbit—through the ophthalmic and the facial veins—the *veins* of the eyelids are tributaries of two systems. Those from the deeper structures (conjunctiva, Meibomian glands), the *retrotarsal veins*, empty into the branches of the ophthalmic, while those draining the more superficial parts of the eyelid, *pretarsal veins*, are tributary to the frontal and facial veins medially and to the supraorbital and superficial temporal laterally. Since not only the supraorbital, but also the frontal veins communicate with the ophthalmic system, the blood is carried off by way both of the orbital and facial channels.

The *lymphatics* of the eyelids are arranged in two sets, a pretarsal and a posttarsal, the net-works of which are connected by vessels which pierce the tarsi. The

former receives lymph from the skin and muscles, the latter from the Meibomian glands and the conjunctiva. The larger vessels on the outer side pass to the pre-auricular and parotid lymph-nodes, and those on the inner or mesial side follow the tributaries of the facial vein and enter the submaxillary lymph-nodes.

Nerves of the Eyelids.—The *sensory nerves* are branches of the ophthalmic and superior maxillary divisions of the trigeminal. The upper lid is supplied mainly by the frontal and supraorbital nerves, the lower lid by the infraorbital nerve. On the nasal side these nerves are supplemented by twigs from the supra- and infratrochlear branches of the ophthalmic, and on the outer side by terminal filaments from the lachrymal nerve. The main branches lie between the tarsi and the orbicularis muscle, sending branches forward to the skin and backward through the tarsi to the conjunctiva and Meibomian glands. In addition a *marginal plexus* is formed near the edge of each lid, which supplies the adjacent parts and the follicles of the cilia.

The *motor nerve* to the levator palpebræ is a branch of the superior division of the oculomotor nerve; the orbicularis palpebrarum is supplied by the facial, and the involuntary muscle of the lids by fibres from the sympathetic.

Practical Considerations.—*The Eyebrows.*—The hair of the eyebrows may be absent, dark brows may show white patches (piebald eyes), or they may be entirely white, as in albinos. Incisions in this area, as for neurectomy in supra-orbital neuralgia, should be made in the line of the brow and within the limits of the hair, so that the scar which results may be hidden.

Dermoid cysts occur in the line of the orbito-nasal fissure of the fœtus, and are most frequent near the outer end of the brow, under the orbicularis palpebrarum, next to the periosteum. Usually they are no larger than a cherry, and in some instances lie deep in the orbit, when they would be difficult of diagnosis. More rarely they occur at the inner angle of the orbit, when they may be connected with the dura. In such cases they would be difficult of removal and might be confused with meningoceles.

Epicanthus is a crescentic fold of skin lying over the inner canthus and the inner end of the palpebral fissure. It may be associated with a congenital defect in the bridge of the nose. In many children a slight tendency to it is seen before the bridge of the nose has reached its full development, while in those races which have little or no bridges to their noses, a slight epicanthus is normal. Until this condition is suspected, these children are often thought to have convergent squint, because the cornea is nearer to the skin than in a normal eye.

Very rarely the lids may fail to develop (ablepharia); less rarely a cleft in the margin of the lid is seen, usually to the median side of the centre of the lid (coloboma), and most frequently in the upper lid. Sometimes the eye has a uniform covering of skin which replaces the lids, no palpebral fissure being present. This is probably due to a persistence of the early fœtal condition, in which the two lids are adherent. It is called *ankylo-blepharon.*

Lagophthalmus is an incomplete closure of the lids, and is sometimes congenital, sometimes the result of paralysis of the facial nerve which supplies the orbicularis muscle. Voluntary contraction of this muscle will usually close the lids in the lesser degrees of the congenital variety, but in sleep they are not closed. Since the eye turns up as the lids are brought together, the cornea is in large part concealed.

Ptosis is a drooping of the upper lid, and when congenital is usually associated with epicanthus, and is bilateral. The forehead is often wrinkled from the effort of the occipito-frontalis muscle to aid the orbicularis in lifting the lid. The head is usually thrown back and the eyes depressed to bring the sensitive part of the retina and pupil in line with the object to be seen.

Blepharospasm is an irritable spasm of the orbicularis closing the lids, and is usually due to disease of other parts of the eye.

The *skin* of the lids is the thinnest in the body and is very loosely applied, through the loose areolar subcutaneous tissue. It therefore wrinkles easily, is readily deformed by scars, and is a favorable field for plastic operations. If cicatricial contraction everts the lower lid, as it often does, the condition is known as *ectropion.* More rarely contraction of the conjunctiva after ulceration or injury inverts a lid,

producing *entropion*. The eyelids become œdematous or ecchymotic from slight causes, and in erysipelas are markedly swollen, closing the lids, or in severe cases may become gangrenous, the exudate interfering with the blood-supply.

Herpes zoster is sometimes seen along the cutaneous distribution of the frontal and nasal branches of the trigeminal nerve. It is found on the forehead, lids, nose, and even the cornea. The iris, ciliary body, or choroid may be involved, since through the lenticular ganglion, the nasal nerve supplies these structures. The cause is an inflammation of the trunk of the trigeminal nerve, the Gasserian ganglion, or the lenticular ganglion.

Hordeolum or *stye* is a suppuration of one of the sebaceous glands (Zeiss's glands) associated with the follicles of the eyelashes. A *chalazion* is an affection of one of the Meibomian glands, with occlusion of the duct and retention of the secretion. There is often no inflammation present. For this reason, and because of its situation on the under surface of the tarsal cartilage, it is often not noticed until it reaches considerable size and shows through the lid. Normally the cilia or eyelashes curve away from the surface of the eyeball. Sometimes from inflammation, most commonly in trachoma or granular lids, they take the opposite direction and irritate the cornea (trichiasis or wild hairs).

The Conjunctiva.—Congenital fatty growths occur rarely in the outer part of the upper conjunctival sac. Dermoids and nævi have also been seen in the conjunctiva. This membrane covers the anterior third of the eyeball, and where it passes to the lids forms the fornices. Because the upper fornix is deeper than the lower, being therefore turned less easily, foreign bodies are removed from the upper sac with greater difficulty. These particles strike first on the surface of the globe, and are usually brushed down into the lower sac by the upper lid. They frequently, however, catch in the conjunctiva of the ball or of the upper lid, and are held in the conjunctival sac only when they get above the upper retro-tarsal fold, where, if not removed, they may set up a chronic inflammation, or remain unnoticed. They have been found there months or even years afterward, entirely embedded in the outgrowths of the inflamed conjunctiva (Fuchs).

A *pterygium* is an elevated layer of conjunctiva and subconjunctival tissue, triangular in shape with its apex near the edge of the cornea, and its base usually towards the inner canthus. It tends to progress towards the pupil, but may stop anywhere short of it.

A *pinguecula* is a yellowish elevation of conjunctiva, to the inner side of the cornea, sometimes to the outer side. It corresponds to the part of the conjunctiva constantly exposed in the interpalpebral fissure, which therefore undergoes a change in structure. That at the inner side is most marked and may become a pterygium later.

The scleral portion of the conjunctiva is loosely applied to permit of free motion of the ball. Near the margin of the cornea it becomes more fixed, and should be caught there by the forceps in the effort to fix the eye when operating upon it. The palpebral portion is more firmly attached, especially at the back of the tarsal plates where it is more vascular, and where paleness is taken to indicate a general anæmia.

In fractures of the base of the skull involving the roof of the orbit the hemorrhage into the orbital tissues shows first under the conjunctiva of the globe (subconjunctival ecchymosis). It finds its way under the conjunctiva of the lids later because that is more firmly attached, and unless the lid is lifted, it will first be noticed at the margin of the lid, after which it may grow upward under the skin. This is due to the fact that the orbito-tarsal or palpebral ligament passes between the margin of the orbit and the upper edge of the tarsal plate like a curtain and prevents the progress of the blood forward to the skin until it has first passed down behind the tarsal plate and under its lower margin. Owing to the thinness of the conjunctiva, oxygen permeates it more readily than it does the skin, so that blood under it retains its redness instead of becoming dark, as under the skin of the lid in ordinary "black eye."

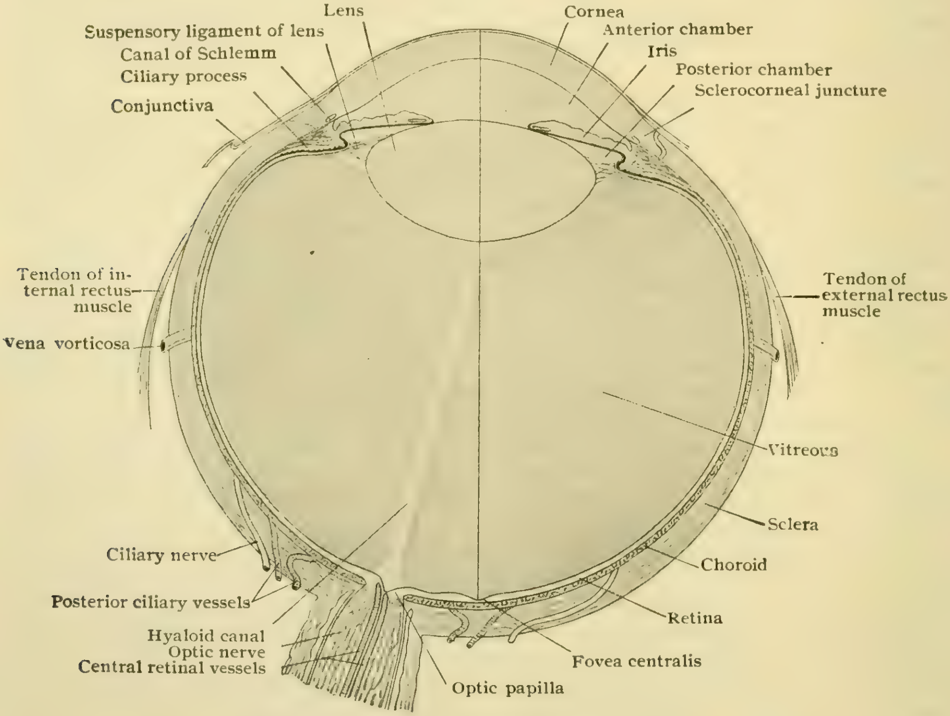
THE EYEBALL.

The eyeball is situated in the anterior part of the orbit, about 2 mm. nearer the lateral than the nasal wall, and slightly nearer the superior than the inferior wall. A line drawn from the superior margin of the orbit to the inferior is tangent to

the surface of the cornea. The axes of the eyeballs are practically parallel, when fixed on a distant object, but the optic nerves converge considerably, so that they enter the eyeball from 2–3 mm. to the nasal side of the posterior pole of the eye. The general form of the eyeball is that of a sphere, but in sagittal section it is found to be composed of the segments of two spheres, an anterior smaller segment, corresponding to the transparent cornea, which has a radius of from 7–8 mm. and a posterior opaque segment, corresponding to the sclera, with a radius of 12 mm. The junction between the two segments is marked externally by a broad, shallow groove, the *sulcus scleræ*, which is filled by the scleral conjunctiva.

The *diameters of the eyeball* measure approximately as follows: the antero-posterior, 24.2 mm.; the vertical, 23.2 mm.; and the transverse, 23.6 mm. Its shape is, therefore, that of a spheroid somewhat flattened from above downward, and from

FIG. 1202.



Diagrammatic horizontal section of right eye. × 3½.

side to side. The diameters are slightly greater in the male than in the female, and vary according to the refractive power, being longer in nearsighted or myopic, and shorter in oversighted or hyperopic eyes.

The eyeball consists of three concentric coats or tunics: (1) the *external* or *fibrous tunic*, composed of the *sclerotic* and the *cornea*; (2) the *middle* or *vascular tunic*, which is pigmented and partly muscular, and is composed, from behind forward, of the *choroid*, the *ciliary body*, and the *iris*; and (3) the *inner* or *nervous tunic*, the *retina*, an expansion of the brain, which contains beside the nerve-cells and the nerve-fibres the specialized neuroepithelium for the reception of visual stimuli.

Within these tunics are enclosed the refracting media, the *crystalline lens*, the *aqueous humor* and the *vitreous body*.

Practical Considerations.—*Congenital anomalies* may affect the whole eye, the appendages, or the individual structures of the eye.

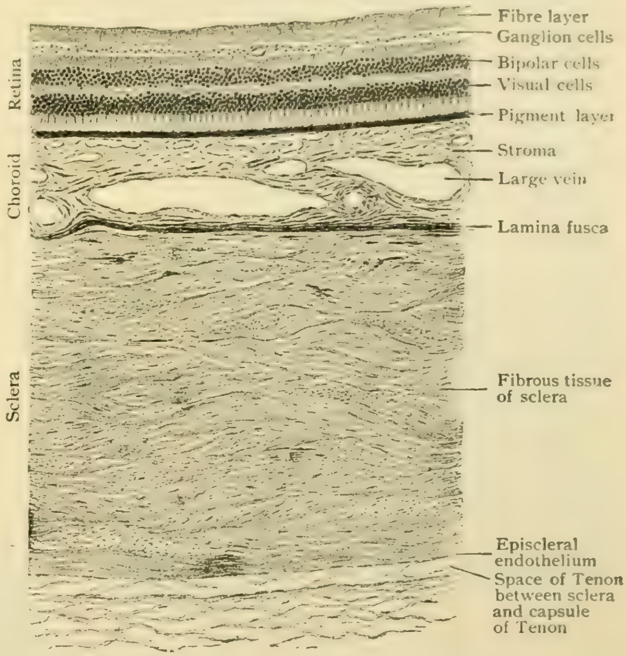
The eye may be *congenitally absent*, on one or both sides (anophthalmos). In some cases of apparent absence the eyeball has been found to be exceedingly small

(microphthalmos) and situated deep in the orbit near the optic foramen. The patient may otherwise be entirely normal; or other developmental errors, as hare-lip or cleft-palate may be present. In some instances where no eyeball was found, the optic nerve had not entered the orbit, and in others the chiasm had not formed, the primary optic vesicle having failed to develop.

Multiple eyes occur in some monsters. As digits sometimes bifurcate to form supernumerary digits, so the cephalic end of the embryo may divide, giving rise to two heads. These may fuse, when, according to the extent of fusion, there will be four, three, or two eyes; or if both the orbits and the eyes fuse there may be only one eye (cyclopia).

The actual size of the eye in man varies little, the apparent size depending chiefly upon the projection from the orbit and the part exposed between the lids. The variation in different animals depends rather upon the necessity for acuteness of vision than upon the size of the animal. The larger the globe the farther the cornea and lens from the retina, and therefore the larger and more distinct the image on the retina of the object seen. The more active the animal the greater is the necessity for acuteness of vision, and therefore the larger the eye. The eyes of birds are proportionally larger than those of other animals. Nocturnal animals, such as the owl, have large eyes. The large retinal image probably compensates for the scarcity of light, to which they are accustomed.

FIG. 1203.



Section of three coats of eyeball, about five millimeters from optic papilla; capsule of Tenon seen below sclera. × 40.

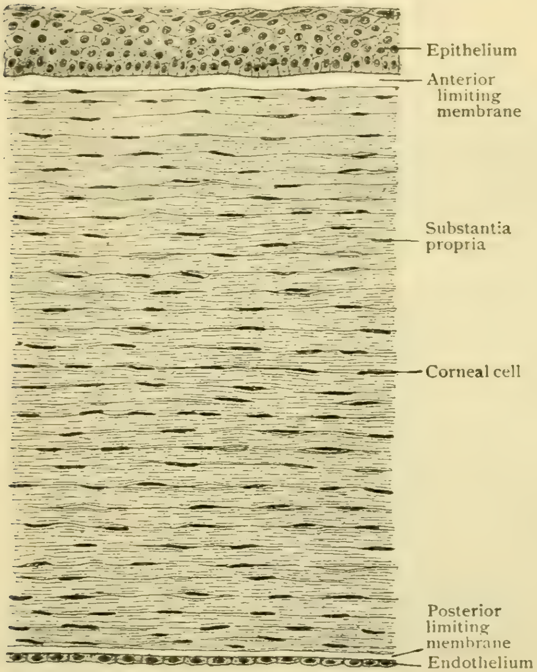
THE FIBROUS TUNIC.

The Sclera.—The sclera, or *sclerotic coat*, is a firm, dense fibrous coat which forms the posterior four-fifths of the outer coat of the eye, being closely connected with the sheaths of the optic nerve posteriorly, and joining in front with the cornea. In the neighborhood of the optic nerve it measures 1 mm. in thickness, and gradually becomes thinner toward the equator, until, just posterior to the attachment of the tendons of the ocular muscles, it measures only .4 mm. After receiving the expansions of these tendons it again becomes thicker and reaches a thickness of .6 mm. In children and in individuals who have thin scleræ and deeply pigmented eyes, the sclera possesses a bluish white color, while in old age it assumes a yellowish tinge. The optic nerve passes through this tunic at a position 1 mm. below and from 2.5–3 mm. to the inner side of the posterior pole of the eye; the canal is partially bridged over by interlacing fibrous bundles, the *lamina cribrosa*, which are intimately associated with the supporting tissue of the nerve. Grouped around the nerve entrance are small openings for the ciliary nerves and posterior ciliary arteries, and toward the equator four or five for the *venæ vorticosæ* which emerge from the choroid.

Structure of the Sclera.—The sclera is composed of interlacing bundles of white fibrous tissue, which on the outer and inner surface have chiefly a meridional direction, while the central bundles form a fairly regular alternation of circular and

meridional lamellæ. The tissue yields gelatine on boiling. With the fibrous bundles is associated a rich net-work of fine elastic fibers. The clefts between the lamellæ contain irregularly stellate connective tissue cells—the *scleral corpuscles*. On the inner surface of the sclera many of these cells are pigmented and give it a brownish color. This layer—the *lamina fusca*—forms with the underlying choroid a narrow lymph-space, the *suprachoroidal lymph-space*, both walls of which, together with the fine connective tissue trabeculæ which cross it, are lined with endothelial cells. The outer surface of the sclera, from the optic nerve entrance to the attachment of the ocular muscles, is similarly covered with endothelial plates, and forms part of the lining of Tenon's lymph-space. Anterior to the muscle-insertions it is covered with a loosely meshed connective tissue, the *episcleral tissue*, which is richly supplied with blood-vessels, nerves and lymph-vessels, and is continuous with the subconjunctival tissue of the *conjunctiva scleræ*.

FIG. 1204.



Section of human cornea. × 85.

The *blood-vessels* of the sclera arise from the arteries which perforate it to supply the vascular coat of the eye, viz: the anterior and posterior ciliary arteries. They form a wide meshed net-work on the surface of the sclera, which sends anastomosing vessels to a deeper lying set in the substance of the membrane. In the neighborhood of the optic nerve entrance the branches of the short posterior ciliary arteries form an arterial circle, the *circulus Zinni*, which sends branches to the optic nerve and choroid, and is therefore of great importance in establishing an anastomosis between the choroidal circulation and the arteria centralis retinæ which supplies the retina.

The *veins* of the sclera empty into the anterior and posterior ciliary veins, and into the venæ vorticosæ. At the junction of the cornea and sclera is an important circular venous channel, the *canal of Schlemm*, which will be described later. The lymphatics of the sclera are represented by the intercommunicating cell-spaces, which communicate with the suprachoroidal and suprascleral lymph-spaces, and anteriorly with the spaces of Fontana, at the sclero-corneal angle.

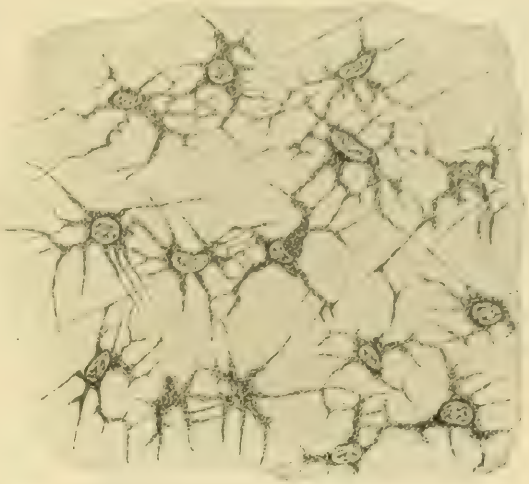
The *nerves* of the sclera are derived from the ciliary nerves during their course between the sclera and the choroid, their terminal filaments being distributed to the vessels, and also as a fine tortuous net-work between the bundles of the scleral tissue.

The relations of the sclera to the optic nerve sheaths will be considered in the description of the optic nerve entrance (page 1470).

The Cornea.—The cornea forms the anterior one-fifth of the fibrous tunic of the eyeball, and, although composed, like the sclera, of bundles of connective tissue, is transparent and allows rays of light to enter the eyeball. Its anterior surface is nearly but not quite circular, measuring 11.9 mm. in its greatest transverse diameter, and 11 mm. in its vertical diameter. The posterior surface is circular and measures 13 mm. in diameter. The sclera therefore encroaches more upon the cornea anteriorly than posteriorly, so that the cornea fits into a groove in the sclera. The radius of curvature of the anterior corneal surface is about 7.7 mm., that of the horizontal meridian being slightly greater (7.8 mm.) than that of the vertical. The

radius of curvature of the posterior surface is only 6 mm.; the cornea is consequently thicker in the periphery than at the center, in the proportion of 1.1 mm. to .8 mm. The degree of curvature varies in different individuals and at different periods of life, being greater in youth than in old age. As the radius of curvature of the sclera, with which its bundles are continuous, is 12 mm., the cornea rests upon the sclera as a watch-glass upon a watch. At the junction of the two membranes, on the outer surface, is the shallow groove, the *sulcus scleræ*.

FIG. 1205.

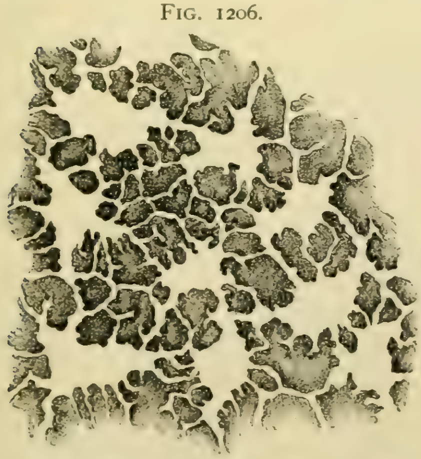


Corneal corpuscles (connective tissue cells), surface view. × 350.

Structure of the Cornea.—The cornea is composed of five distinct layers, which from without in are: (1) the *anterior epithelium*, (2) the *anterior limiting membrane*, (3) the *substantia propria*, (4) the *posterior limiting membrane*, and (5) the *posterior endothelium*.

The **anterior epithelium** of the cornea is continuous with that covering the surface of the adjacent conjunctiva scleræ. It is of the stratified squamous variety, usually five cells deep in man, and measures .045 mm. in thickness at the center, and .080 mm. at the periphery. The deepest cells are columnar in form, with broad basal plates resting upon the anterior limiting membrane, to which they are firmly attached by means of minute projections which roughen the anterior surface of the latter. The outer parts of the basal cells contain the nucleus and fit into corresponding depressions in the cells of the superimposed layers. The middle layers are composed of irregular polyhedral cells, which usually present fine protoplasmic denticulations, and resemble prickle cells. The superficial layers consist of flattened cells which lie parallel to the free surface and contain well-staining nuclei.

FIG. 1206.



Corneal spaces, after action of argentic nitrate; surface view. × 350.

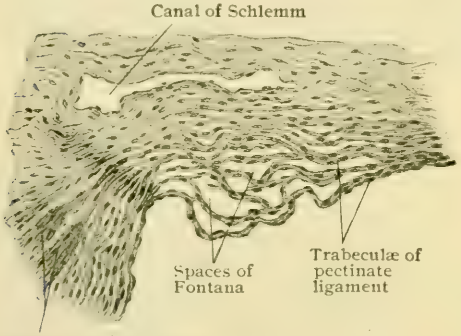
The **anterior limiting membrane,** or *Bowman's membrane*, is situated immediately below the epithelium, and appears as a homogeneous band, about .02 mm. in thickness at the center and thinner at the periphery, where it terminates without extending into the conjunctiva of the sclera. The membrane may be split into fine fibrillæ by the use of suitable reagents, is connected firmly with the cornea proper by delicate filaments, and is to be considered a special condensation of the latter. It contains no elastic tissue.

The **substantia propria** constitutes the main portion of the cornea, and is made up of interlacing bundles of connective tissue, which are directly continuous with those of the adjacent sclera. The bundles are composed of fine fibrillæ, have a flattened form, and are so disposed as to produce regular lamellæ, about sixty in number, running parallel with the surface. The alternating lamellæ have a direction approximately at right angles to each other and are frequently joined together by

bands, which are especially numerous in the anterior lamellæ, to which the name *fibræ arcuatæ* has been given. The fibrillæ and bundles are held together by an amorphous cement substance, and embedded in it are the cellular elements, the *corneal corpuscles.* These are flattened connective tissue cells, with faintly granular protoplasm, the nuclei of which in the adult are irregular and show nucleoli. The cells are provided with branching processes which anastomose with those of other cells both on the same level and with those between adjacent lamellæ, and so constitute a continuous net-work of protoplasm, upon which the nutrition of the cornea largely depends. They have been described as occupying part of a regular system of cell-spaces and canaliculi, but most recent investigations seem to indicate that during life they fill out the spaces completely, and leave no gaps through which fluid can pass. Occasionally leucocytes or wandering cells are found between the fibrous elements.

The **posterior limiting membrane**, also known as *Descemet's membrane*, the *membrane of Demours*, or the *posterior elastic membrane*, is a practically homogeneous band, which varies in thickness from .006—.012 mm. at the center and at the periphery respectively. It is less firmly united to the substantia propria than is the anterior limiting membrane, and is less easily affected by acids, alkalies, boiling water and other regents. It resembles elastic tissue and is very firm and resistant to injury or perforation from inflammation. At the periphery, Descemet's membrane splits up into bundles of fine fibres, which are gradually strengthened and form a series of firm connective tissue trabeculæ, some of which form the point of attachment of the ciliary muscle; others run into the iris, and still others constitute the outer wall of a circularly disposed venous channel, the **sinus circularis iridis**, or **canal of Schlemm**. These fibres are known as the **ligamentum pectinatum iridis** and form the outer boundary of the angle of the anterior chamber. They are incompletely covered with endothelial cells and enclose between their loose meshes the **spaces of Fontana**. These, better developed in lower animals than in man, directly communicate with the anterior chamber, and thus form an important path for filtration of fluid from the interior of the eye, by way of the canal of Schlemm, into the anterior ciliary veins.

FIG. 1207.



Meridional section through angle of anterior chamber showing spaces of Fontana between relaxed fibres of pectinate ligament and canal of Schlemm. × 65.

The **posterior endothelium** covers the inner surface of Descemet's membrane. It is composed of a single layer of flattened polygonal cells, the nuclei of which often extend above the level of the cell body. The cells are connected together by delicate protoplasmic processes and are continuous with the cells lining the spaces of Fontana and the anterior surface of the iris. With Descemet's membrane they constitute a barrier to the filtration of fluid from the anterior chamber into the cornea, although its passage by diffusion is possible.

The *blood-vessels* of the normal cornea are limited to a peripheral zone, from 1–2 mm. in width, where the terminal twigs of the episcleral branches of the anterior ciliary arteries end in loops (Fig. 1215), from which the blood is carried to the anterior ciliary veins. The remainder of the cornea is free from blood-channels.

The *nerves* of the cornea are exceedingly numerous. They are branches of the long and short ciliary nerves, from 40 to 45 in number, and form a plexus which surrounds the margin of the cornea (**plexus annularis**). Those which supply the anterior part of the cornea anastomose first with the conjunctival nerves. Entering the cornea, they are accompanied for a distance of 1 mm. by a perineural lymph-sheath, and then losing this and their medullary sheath, they form within the corneal stroma a number of plexuses at various depths. A few of the fibres pass backward

and supply the posterior layers. Fully two-thirds, however, after forming a *fundamental plexus*, push forward and send *perforating branches* through Bowman's membrane and form on its surface a *subepithelial plexus*, the minute fibres of which pass in a radial manner toward the center of the cornea. From this plexus fine fibrils ascend between the epithelial cells, and end either as varicose fibrils, or in connection with special end-bulbs (the *intraepithelial plexus*). In the substantia propria the branches from the fundamental plexus, after forming complex secondary plexuses, end as naked fibrillæ between the lamellæ, probably in close connection with the corneal corpuscles.

Practical Considerations.—The external or fibrous covering of the eyeball consists of the sclera and cornea, and is the protective covering. The posterior five-sixths is made up of *sclera*, which in some animals becomes cartilaginous or even bony. In the human eye the average normal tension within the globe is equivalent to a column of mercury 26 mm. high. Excessive intraocular tension occurs under pathological conditions (glaucoma) and may reach 70 mm. or more. The more delicate structures then suffer severely and unless the pressure is relieved they are functionally destroyed. The sclera is thickest and strongest posteriorly and gradually grows thinner as it passes forward. Immediately behind the insertions of the recti muscles it is thinnest (.4 mm.). Here bulging is most likely to occur from internal pressure (anterior scleral or ciliary staphyloma), or pus within to burrow through. In front of this zone it is reinforced by expansions from the insertions of the muscles, and would seem therefore to be stronger, although it is in this region, just back of the margin of the cornea, that ruptures are most likely to occur from external violence.

Ruptures of the sclera occur close to—within 3 mm. of—the corneal margin and concentric with it, because in most cases, as Fuchs points out, the application of the force does not lie in the centre of the cornea, but in the sclera below and to the outer side of the cornea. The greatest expansion of the sclera takes place in its upper half near the margin of the cornea, at which place, therefore, the sclera ruptures.

This region is the so-called *dangerous* zone of the eyeball, because the iris and ciliary body correspond to it, and in wounds involving these structures, sympathetic ophthalmia frequently results, often leading to destruction of both eyes. Besides the *anterior staphylomata* of the sclera, we may have the *equatorial* and the *posterior*. The *equatorial* develops at the spots where the venæ vorticosæ penetrate and thus weaken the sclera about the equator of the globe.

The *posterior* is assumed to be the result of a congenital weakness of the sclera. The *anterior* or *equatorial* can be seen or palpated, while the *posterior* is recognized only by demonstrating the existence of a high degree of short-sightedness, which is due to an increase of the sagittal axis of the eyeball.

Rupture of the sclera is usually the result of a blow on the eye. The ciliary body and anterior portion of the choroid are frequently forced into the wound, the vitreous and aqueous chambers contain blood, while the lens may find its way through the rent and lie under the conjunctiva, which may or may not be torn. Rarely the rupture will be in the posterior portion of the globe.

Congenital opacities of the *cornea* may occur and may be complete or partial. In some of the cases reported of the complete variety the anterior elastic lamina was absent, and the anterior layers of the stroma were not laminated as usual, but crossed each other, and among them were found blood-vessels. The partial varieties may consist of a dense white opaque ring at the margin of the cornea, as though the sclera had extended into the cornea, or they may resemble an arcus senilis in which a perfectly clear strip of cornea divides the opaque line from the margin of the sclera.

The cornea in health is transparent, and almost all pathological lesions render it opaque. It is the most exposed and therefore the most frequently injured part of the eye. Wounds of the cornea heal readily under favorable circumstances, showing that its nutrition is good, although there are no vessels in it, except within 1–2 mm. of its margin. When the cornea is inflamed, however, new vessels may form from those at the margin and extend a variable distance inward. Under the influence of

irritating conditions a superficial inflammation may develop, covering the cornea with a new vascular tissue (pannus), the deeper layers still being bloodless. Owing to a very free nerve-supply the cornea is very sensitive.

As in the sclera, weakness of the cornea leads to bulging, from internal pressure. The causes of weakness may be congenital and acquired. *Congenital conical cornea* or *kerataconus* may occur, and it is believed that some congenital defect predisposes to the same condition that occurs in the adult. It is not due to weakening from previous ulceration or injury of the cornea, and the exact cause is not known.

A *staphyloma* of the cornea is a similar condition in which the protuberance is due to the distention of a cicatrix, to the posterior surface of which the iris may be attached (anterior synechiæ of the iris). The cicatrix involves all the layers of the cornea, and is the result of a perforating ulcer. If the ulcer had been a non-perforating one, and the iris did not adhere to its posterior surface, the protrusion of the cornea would then be called a *keratectasia*.

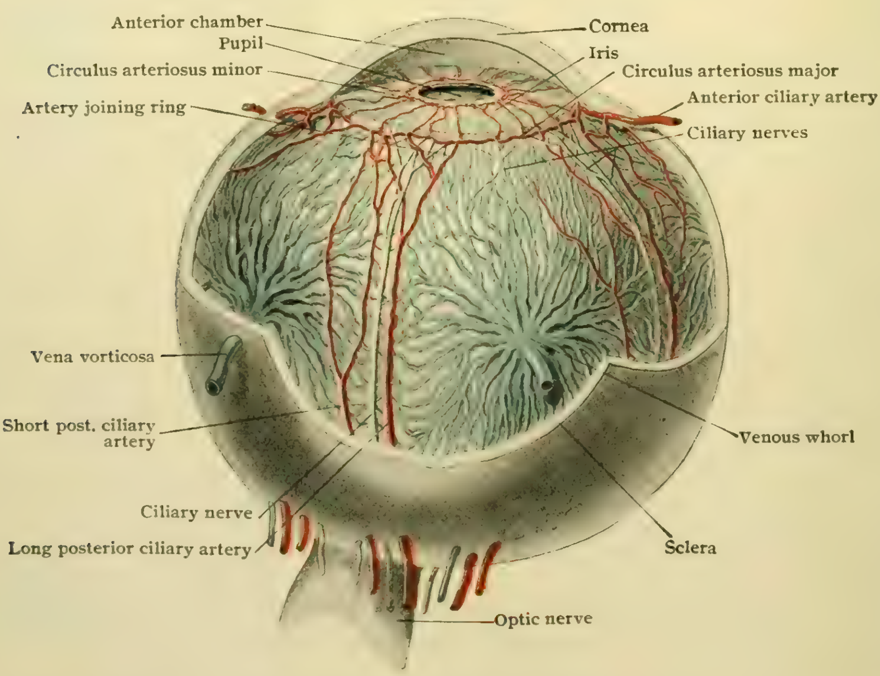
If all the layers of the cornea to the posterior elastic lamina had been destroyed by the ulcer, and this layer had bulged through the weakened spot like a hernial pouch it would be called a *keratocele*.

Arcus senilis is usually a sign of old age. Modern investigation indicates that it is due to a fatty degeneration of the substantia propria, the exact nature of the fatty material being unknown. It first appears as a crescent above, then below, and finally a complete circle is formed. It never interferes with sight. It is occasionally seen in children.

The Vascular Tunic.

The middle or vascular coat of the eye (**tunica vasculosa oculi**), or *uveal tract*, consists of a vascular connective tissue sheath, which lies internal to the outer fibrous

Fig. 1208.



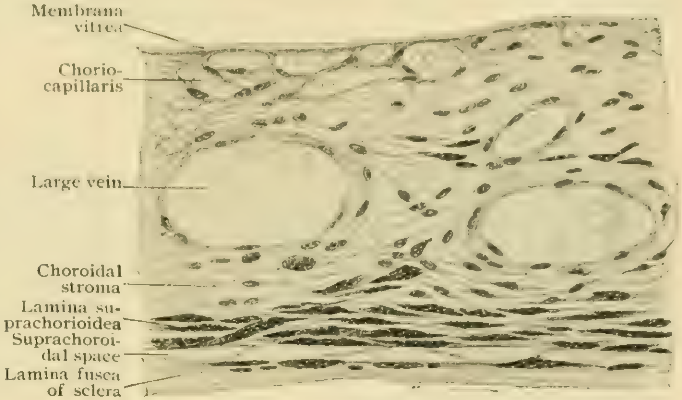
Injected eyeball, showing arrangement of ciliary arteries and of choroidal veins. × 3. Drawn from preparation made by Professor Keiller.

tunic. It extends from the entrance of the optic nerve to the pupil and includes three portions, which from behind forward are the *choroid*, the *ciliary body* and the *iris*. The choroid and ciliary body are in contact with the sclera, but the iris bends

sharply inward and floats in the aqueous humor, incompletely dividing the space anterior to the crystalline lens into a posterior and an anterior chamber.

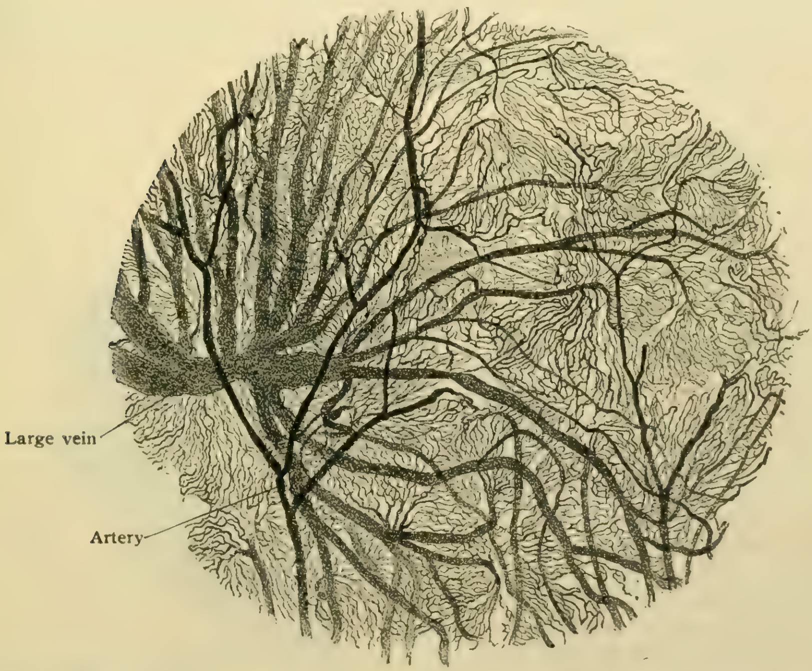
The Choroid.—The choroid (**tunica chorioidea**) forms the posterior two-thirds of the vascular coat. It lies between the sclera and the retina and extends from the optic nerve entrance to the anterior limit of the visual part of the retina at the ora serrata, its main function being to supply nutrition to the nervous tunic. It is a delicate coat, which has a thickness of .1 mm. near the nerve and gradually diminishes in thickness towards the ora serrata, where it measures only .06 mm. The *outer surface* is roughened by the trabeculæ of connective tissue which cross the suprachoroidal lymph-space and connect the choroid with the overlying sclera. The connection is maintained partly also by the larger vessels and nerves, which lie within this space during their course forward and send branches to supply the choroid. The *inner surface* of the choroid is smooth and covered by the pigmented cells of the retina, which are so closely attached that they frequently adhere to the choroid when the membranes are separated. Posteriorly, the choroid helps to form the lamina cribrosa, the fenestrated membrane through which the optic nerve-fibres pass ; anteriorly it is continuous with the ciliary body.

FIG. 1209.



Section of choroid. × 275.

FIG. 1210.

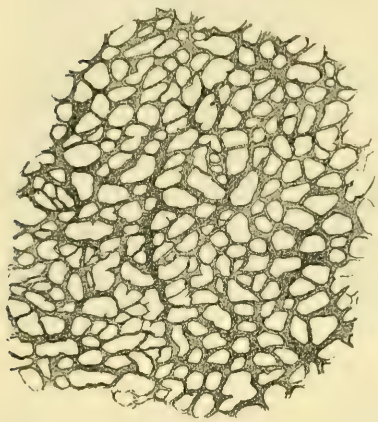


Surface view of injected human choroid, showing venous radicles converging to form larger veins. × 18.

Structure of the Choroid.—The choroid consists of four layers, which from without inward, are: (1) the *lamina suprachorioidea*, (2) the *choroid proper*, which contains the larger vessels, (3) the *choriocapillaris*, or layer of fine capillaries, and (4) the *membrana vitrea.*

The **lamina suprachorioidea** forms the outer boundary of the choroid and connects it with the sclera. It is composed of interlacing bundles of fibrous connective tissue, which are strengthened by a rich network of elastic fibres. The cellular elements consist of (*a*) flattened endothelial plates, which line the lymph-clefts and cover the connective tissue trabeculæ connecting the choroid and the sclera by traversing the suprachoroidal lymph-space; and (*b*) large, irregularly branched connective tissue cells, the *chromatophores*, which are conspicuous on account of their deeply pigmented protoplasm. The lamellæ of the suprachoroid continue, without definite boundary, into the subjacent choroidal stroma.

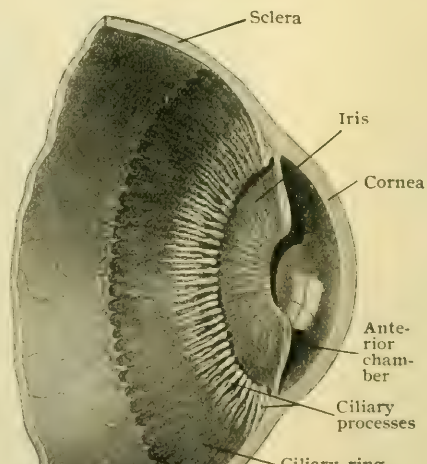
FIG. 1211.



Portion of injected choriocapillaris layer of human choroid. × 130.

The **choroid proper,** as the choroidal stroma is called, has the same general structure as the suprachoroidal layer, but the connective tissue elements are denser and support a large number of blood-vessels, between which are placed the stellate chromatophores. The largest vessels occupy the outer part of the coat, and are chiefly venous. They are surrounded with perivascular lymph-sheaths, and converge in peculiar whorls to form four or five large trunks, the *venæ vorticosæ*, which pierce the sclera in the equatorial region and, running obliquely backward, drain not only the choroid, but partly also the ciliary body and iris. The arteries are derived from the short ciliary vessels, which pass through the sclera near the optic nerve. They lie internal to the veins and their walls contain longitudinally disposed muscular fibres in addition to the customary circular ones.

FIG. 1212.



Anterior part of sagittally sectioned eye-ball, showing iris, ciliary processes and ring and ora serrata. × 3.

The **choriocapillaris,** or *membrane of Ruysch*, is composed of the fine capillaries of the choroidal vessels, which form an extremely fine mesh-work embedded within a homogeneous, nonpigmented matrix. Between the choriocapillaris and the layer of larger vessels is a narrow boundary zone of closely woven fibro-elastic strands, which is nearly free from pigment. In some animals this layer possesses a peculiar metallic reflex and is known as the *tapetum fibrosum;* in carnivora its iridescent appearance is due to the presence of cells containing minute crystals (*tapetum cellulosum*).

The **membrana vitrea,** or *membrane of Bruch*, the innermost layer of the choroid, measures only .002 mm. in thickness. It separates the choriocapillaris from the retina and is composed of two strata, an inner homogeneous one, probably an exudation product of the retinal pigment cells, and an outer highly elastic portion.

The *lymphatics* of the choroid are represented (1) by vessels which begin in the lymph-spaces between large blood-vessels, and are in communication with the spaces between the suprachoroidal lamellæ, and (2) by the perivascular lymph-spaces of

the veins, which begin between the meshes of the choriocapillaris, the two systems being separate.

The *nerves* of the choroid arise from the long and short ciliary nerves during their course on the inner surface of the sclera. They form a plexus within the lamina suprachorioidea, which contains groups of ganglion cells, and sends numerous nonmedullated fibres chiefly to the muscular coats of the arteries. A few ganglion cells are found along the blood-vessels. The choroid contains no sensory nerve-fibres.

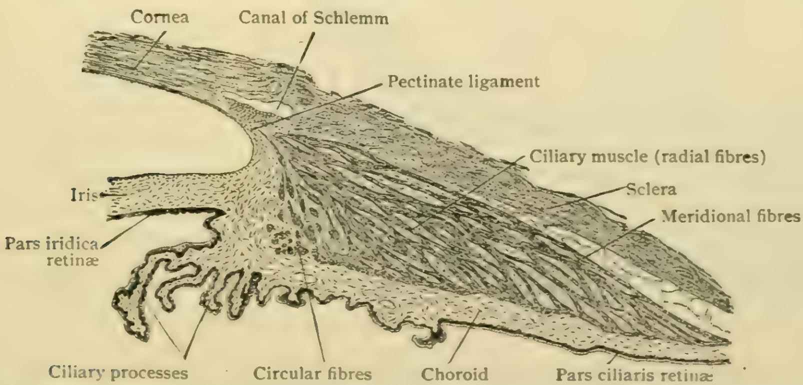
FIG. 1213.

Sections of ciliary processes; *A*, from anterior; *B*, from posterior part; two epithelial layers, pigmented and clear, of pars ciliaris retinæ cover choroidal stroma. × 80.

The Ciliary Body.—The ciliary body (**corpus ciliare**), the middle portion of the vascular tunic, extends from the ora serrata to the sclero-corneal junction. Sections through the eyeball in a meridional direction (Fig. 1214) show that it has a triangular form. The outer side is in apposition to the sclera, the inner is covered by the pigmented extension of the retina, and the short anterior side, at right angles to the outer, extends inward from the pectinate ligament toward the lens.

The ciliary body presents three subdivisions; the *ciliary ring*, the *ciliary processes* and the *ciliary muscle*.

FIG. 1214.



Meridional section of ciliary region, showing ciliary body with its muscle and processes. × 40.

The **ciliary ring**, or *orbiculus ciliaris*, consists of a smooth band of tissue, 4 mm in width, in advance of the ora serrata. It differs in structure from the choroid in the absence of the choriocapillaris, its vessels running in a longitudinal direction and returning the blood from the iris and ciliary body to the venæ vorticosæ. On its inner surface, delicate meridionally placed folds make their appearance, by the union of which the ciliary processes are formed.

The **ciliary processes** constitute the remainder of the inner portion of the ciliary body. They form an annular series of folds, between 68 and 80 in number, which surround the lens and act as points of attachment to its suspensory ligament.

Commencing by the union of several plications of the orbiculus ciliaris, they rapidly increase in height and breadth, until they reach an elevation of from .8–1 mm., and then fall suddenly to the iris level. They consist of a rich net-work of vessels embedded in a pigmented connective tissue stroma, like that of the choroid. The inner surface is covered with a homogeneous membrane, which is continuous with the membrana vitrea of the choroid, on the inner surface of which is placed the double layer of cells representing the ciliary portion of the retina (*pars ciliaris retinæ*). Each ciliary process is composed of a number of irregularly projecting folds which increase in height as the iris is approached.

FIG. 1215.

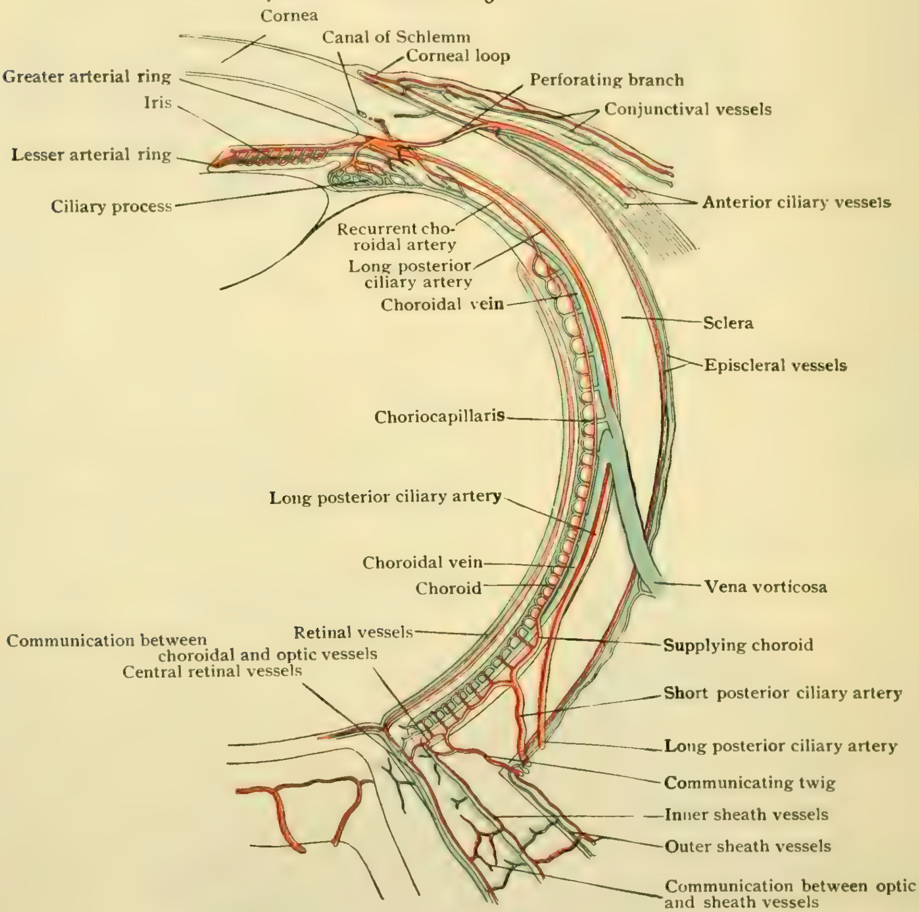


Diagram illustrating circulation of eyeball. (*Leber.*)

The **ciliary muscle** occupies the outer portion of the ciliary body, lying between the sclera and the ciliary processes. It forms an annular prismatic band of involuntary muscle, which in meridional sections has the form of a right-angled triangle, the hypothenuse being the outer side, next to the sclera, and the right angle facing the lens. Its main fibres arise from the sclera and pectinate ligament, at the corneo-scleral junction internal to the canal of Schlemm, and run in a *meridional* direction backward along the sclera to be inserted into the choroidal stroma (hence their name, *tensor chorioideæ*). The inner angle of the triangle, at the base of the iris, is occupied by a band of *circularly* disposed fibres, which constitute the *circular ciliary muscle of Müller.* Between the circular and meridional portions, the fibres assume a *radial* direction and are separated by considerable connective tissue, which in the deeply pigmented races may contain many branched

pigmented cells, but in the white races is free from pigment. In hyperopic eyes the circular bundles are usually better developed than in myopic ones.

The *blood-vessels* of the ciliary body arise from the anterior and the long ciliary arteries. They form a ring around the root of the iris, the *circulus arteriosus iridis major*, from which vessels are sent inward to supply the iris, ciliary muscle and ciliary processes. The *veins* from the ciliary muscle empty chiefly into the anterior ciliary veins; those from the ciliary processes, and a few from the ciliary muscle pass backward and become tributary to the *venæ vorticosæ*.

The *nerves* of the ciliary body are derived from the anterior branches of the long and short ciliary nerves, which form an annular plexus within the ciliary muscle. Four sets of fibres probably exist: (1) sensory fibres, largely subscleral in distribution; (2) vasomotor fibres running to the blood-vessel walls; (3) motor fibres supplying the muscle bundles; (4) fibres terminating within the interfascicular tissue of the ciliary muscle.

Practical Considerations.—*Congenital coloboma* of the choroid, as of the iris, usually occurs in the lower part, along the line of the fœtal ocular cleft. In the defect the sclera shows pearly white through the ophthalmoscope, with here and there a little pigment and a few ciliary vessels. The retina is frequently absent, but its occasional presence explains why this area is not always blind.

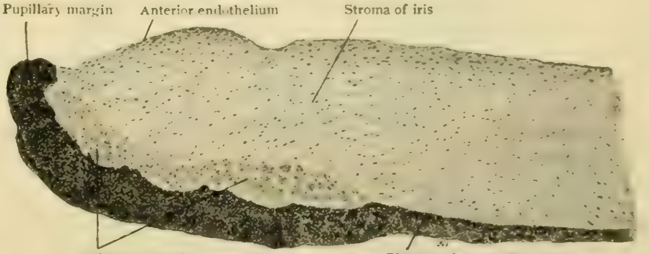
In acute exudative inflammation of the choroid, foci of inflammation are seen scattered over the fundus, and are characteristic. They form yellowish spots between the choroid and retina, and are later converted into connective tissue, binding the choroid and retina together. The two layers become atrophic finally, the layers of rods and cones disappearing. The exudate may extend into the retina and even into the vitreous, producing opacities.

Sarcoma is the common tumor of the choroid and is usually pigmented.

Carcinoma of the choroid is always a metastatic growth, usually a metastasis from a carcinoma of the breast. Adenoma, angioma, and enchondroma of the choroid have been described.

The Iris.—The iris forms the anterior segment of the vascular tunic and is visible through the cornea. Slightly to the inner side of its centre is placed an approximately circular opening, the **pupil.** The periphery of the iris, or ciliary border, is attached to the ciliary body behind and receives fibres from the pectinate ligament anteriorly. The free border, which forms the margin of the pupil, rests upon the anterior surface of the lens. The iris measures 11 mm. in diameter and about .4 mm. in thickness. The pupil varies from 1–8 mm. in diameter. The color of the iris, viewed from in front, varies in different individuals and gives the color to the eyeball. It is dependent partly upon the amount of pigment within the iris stroma, and partly upon the density of the pigmentation of the cells on its posterior surface. In light blue eyes, the stroma contains very little pigment and the posterior pigment layer, seen through it, gives it a bluish tint; whereas in brown eyes the stroma contains so much pigment that the posterior pigment layer is totally obscured and the iris appears brown. The anterior surface is marked by a number of fine, radiating lines, or ridges, which indicate the position of the blood-vessels. Concentric to the pupillary margin, at a distance of from 1–2 mm., is an irregular ridge, the *circulus arteriosus iridis minor*, which divides the iris into a *pupillary* and a *ciliary zone* which are often differently colored. The pupil is surrounded by a narrow black border. The posterior

FIG. 1216.

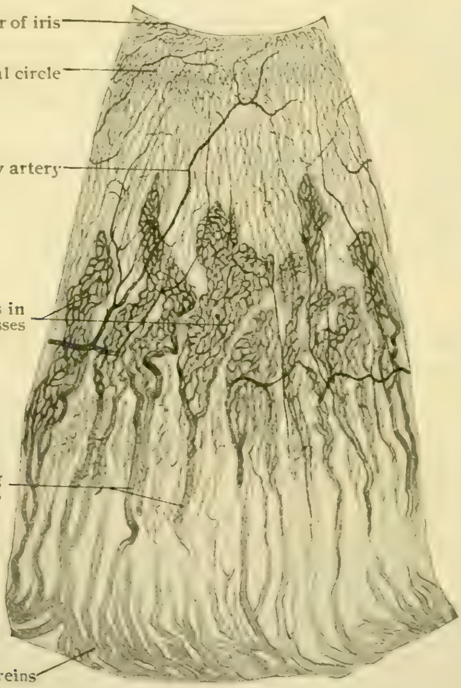


Section of pupillary end of iris. × 210.

surface of the iris presents a series of delicate converging folds, which are intersected by concentric lines.

Structure of the Iris.—Radial sections of the iris show the stroma to be composed of numerous thick-walled blood-vessels, running in a radiating manner from the ciliary border toward the pupil. They are supported by a delicate connective tissue framework, which contains irregularly shaped, branching pigmented cells, many nerves and lymph-spaces. The anterior surface is covered with a single layer of polygonal *endothelial cells*, continuous with those lining Descemet's membrane. Beneath these cells is a condensation of the connective tissue stroma—*the anterior boundary layer*, in which the cells are closely placed. Minute clefts in the tissue form a direct communication between the anterior chamber and the interfascicular lymph-clefts. In very dark irides pigment is found not only within the branched cells, but heaped in irregular masses within the stroma. The muscular tissue of the iris consists of two distinct masses, the *sphincter pupillæ* and the *dilatator pupillæ*.

Fig. 1217.



Injected ciliary processes and iris; vessels are seen from the posterior surface. × 30.

The *sphincter muscle*, is a band of involuntary muscle measuring about .7 mm. in width, which surrounds the pupil and is situated in the vascular stroma, back of the blood-vessels, and separated from the pupil edge by the narrow border constituted by the posterior pigmented layer.

The *dilatator muscle* is formed by a sheet of smooth muscle-fibres in the position formerly described as the *posterior limiting lamella*, or membrane of Bruch. The investigations of Grynfeltt and Heerfordt have settled definitely the question of its existence, and shown that its fibres arise from the outer cells of the retinal pigment layer, on the posterior surface of the iris. They do not reach quite to the pupillary border.

The posterior surface of the iris is covered by the *pigmented layer*, which morphologically represents the anterior segment of the atrophic nervous tunic, or *pars iridica retinæ*. This is continuous with the pigmentary layer covering the ciliary processes, but the cells, disposed as a double layer, are so deeply pigmented as to be indistinguishable without bleaching the tissue. The dilatator muscle is developed from the outer layer of fusiform cells, so that it represents an epithelial (ectoblastic) muscle. The inner cells are larger polygonal elements, which gradually lose their pigment as they approach the ciliary processes. Over the latter they contain no pigment, whereas the outer cells remain pigmented.

The *blood-vessels* of the iris pass radially inward from the *circulus arteriosus iridis major* at the periphery. Near the pupillary border, they form a second ring, the *circulus arteriosus iridis minor*, branches from which supply the sphincter muscle and the pupillary zone. The *venous radicles* unite to form trunks which accompany those from the ciliary processes to empty into the *venæ vorticosæ*.

The *lymphatics* are represented by the interfascicular clefts which communicate with the anterior chamber, with the spaces within the ciliary body, and with the spaces of Fontana.

The *nerves* of the iris are branches of the ciliary nerves. They follow the course of the blood-vessels and, branching, form a plexus of communicating nonmedullated fibres, which supply sensory, motor and vasomotor impulses. The human iris probably contains no ganglion cells.

Practical Considerations.—The iris may be partially or completely absent, when by bringing down the eyebrows and partially closing the lids, the patient will make an effort to shut off the excess of light, as in albinism, and the eye will frequently be nystagmic.

A *congenital coloboma* or deficiency in the iris is usually in the lower part, and may be associated with a corresponding defect in the ciliary body and choroid. The pupil may be eccentric in position (corectopia), unusually small (microcoria), irregular in shape (discoria), or it may be represented by several pupils (polycoria). The pupillary membrane of the fœtus, covering the pupil, not infrequently persists for a short time after birth. A portion of it persisting permanently is one of the commonest congenital anomalies of the eye.

The color of the iris varies according to the amount and location of the pigment in it. When the coloring matter is absent from the stroma, and present only in the posterior layer of epithelium, the eye is blue. If such an iris is thicker than usual the opacity will be greater and the eye will tend to be grayish. When there is pigment only in slight amount in the stroma, the eye is greenish, and when in marked quantity in the stroma, the eye is brown or even black, as in negroes. The deepest tints of brown are usually called black.

In *albinism* there is an absence of pigment in the iris, and in the other parts of the body where pigment is usually found. The eyes are pinkish in color, because the light enters through the tunics and is not absorbed by the choroid and retina, owing to the absence of pigment in it. The retina is therefore intolerant of light, so that the patient tries to shut it out by screwing up the eyebrows and lids, and by contraction of the iris. He will frequently show nystagmus or oscillation of the eyeball, and amblyopia, or subacuteness of vision.

The two eyes are not always of the same color, and even in the same eye, one part of the iris may be blue and another brown (piebald iris). One eye may have its color permanently changed as the result of inflammation, so that the difference in color may be an important diagnostic sign of previous disease.

The iris acts as a colored curtain to shut off excess of light, as more or less light is necessary for the definition of images. Too much light impairs the definition and injures the retina. The pupils are usually of equal size in health, and any marked inequality has a pathological significance. The iris does not hang in a vertical plane, but is pushed slightly forward and supported at its pupillary margin by the lens. If the lens is absent or dislocated, the pupillary margin of the iris may be seen to quiver with the movement of the eyes. The iris in spite of its great vascularity may not bleed much when wounded, probably because of the contraction of its abundant muscular fibres. The iris is continuous with the ciliary body, and through the latter with the choroid, the three taken together making up the uveal tract, or middle tunic of the eye. Any inflammation of the one may easily spread to the others. This usually occurs, but as the inflammation is predominant in one, we speak of an iritis, a cyclitis, or a choroiditis, and not of the whole process as a uveitis. In an iritis the exudation which affects the stroma as well as the anterior and posterior aqueous chambers can be studied by inspection. It thickens and discolors the iris, renders the aqueous fluid turbid, and leaves a deposit on the contiguous surfaces of the cornea and lens. Since the pupillary margin of the iris is in contact with the lens on the posterior surface the exudate causes adhesions of this margin to the lens (posterior synechiæ). Since the pupil is contracted in inflammation, when these adhesions form, dilatation of the pupil normally or under the influence of atropine, gives rise to a very irregular pupil, the unattached portion dilating, the attached portions not. Sight need not be affected if the pupil is large enough. If the whole margin of the pupil is attached to the lens, or the pupil is occluded by exudate, the normal flow of fluid from the posterior to the anterior chamber cannot take place, and glaucoma (*vide supra*),

a disease due to increased intraocular tension from retention results. It is necessary, therefore, in iritis to keep the pupil dilated, so as to prevent such adhesions as far as possible.

THE NERVOUS TUNIC.

The Retina.—The retina, the light perceiving portion of the eye, with its continuation, the optic nerve, in contrast to the other sense organs represents a portion of the brain itself, and develops in close connection with it. It is a delicate membrane, which extends from the optic nerve entrance to the pupillary border. The functionating portion, or *pars optica retinæ*, reaches as far forward as the *ora serrata*, where it terminates as an irregular, wavy line ; anterior to this the retina is represented by an atrophic portion, consisting of the double layer of cells covering the

FIG. 1218.

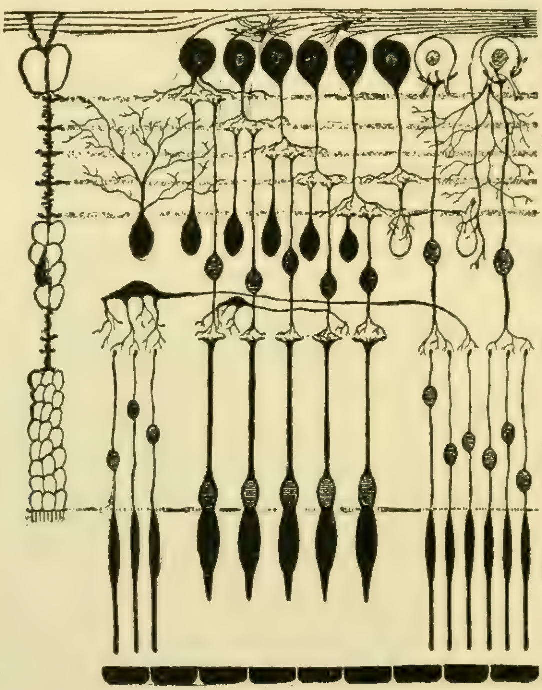


Diagram illustrating structure of retina and relations of three fundamental layers. (*Greeff.*)

ciliary body and the iris, already referred to in the description of these structures, and known respectively as the *pars ciliaris retinæ*, and *pars iridica retinæ*.

The **pars optica retinæ** is closely applied to the inner surface of the choroid and is in contact with the hyaloid membrane investing the vitreous body. It gradually diminishes in thickness from .4 mm. at the posterior pole to .1 mm. near the ora serrata. During life the membrane is transparent and possesses a purplish red color, owing to the presence in its outer layers of the so-called *visual purple;* after death the retina rapidly becomes opaque and has the appearance of a grayish veil. The inner surface is smooth and presents at the posterior pole of the eye, a small circular or transversely oval yellow spot, the *macula lutea*, from 1–2 mm. in diameter. At the centre of the macula is a small depression, the *fovea centralis*, from .2–.4 mm. in diameter, in which position the retina is reduced in thickness to .1 mm.

The *entrance of the optic nerve* forms a conspicuous spot of light color, situated 3 mm. to the nasal side of the macula lutea. This area, called the *optic papilla* or *porus opticus*, is in form of a vertical oval, about 1.5 mm. in its horizontal and

1.7 mm. in its vertical diameter. At its centre is often seen a well-marked excavation, the *optic cup*, from the bottom of which emerge the blood-vessels which supply the retina. Being insensible to visual impulses, the optic entrance corresponds to the "blind-spot."

Structure of the Retina.—The retina is composed of nervous elements which are supported by a specialized sustentacular tissue or neuroglia. Morphologically it must be considered as composed of two lamellæ, which correspond to the outer and inner walls of the optic vesicle (page 1482) from which it is developed. These fundamental divisions of the retina are: (1) the external lamella, the *pigmented layer* on the outer surface; and (2) the internal lamella, which includes the remaining layers of the retina. The inner lamella may be subdivided further into the *neuroepithelial* and the *cerebral* layers. Sections of the retina, made perpendicularly to its surface (Fig. 1220), show under the microscope from without inward the following layers:—

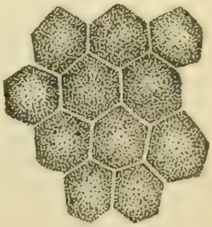
LAYERS OF THE RETINA.

I. OUTER LAYER OF OPTIC VESICLE	1. Pigmented layer	Pigmented layer
II. INNER LAYER OF OPTIC VESICLE	2. Layer of rods and cones 3. Layer of bodies of visual cells or outer nuclear layer	Neuro-epithelial layer
	4. Outer plexiform layer 5. Layer of bipolar cells, or inner nuclear layer 6. Inner plexiform layer 7. Layer of ganglion cells 8. Layer of nerve-fibres	Cerebral layer

To these nervous layers must be added two delicate membranes, (1) the *membrana limitans interna*, which bounds the inner surface of the retina, and (2) the *membrana limitans externa*, which lies between the outer nuclear layer and the layer of rods and cones. These membranes represent the terminal portions of the supporting neurogliar fibres, or *fibres of Müller*.

The **pigmented layer**, formed of deeply pigmented cells, constitutes the most external layer of the retina and represents the outer wall of the fœtal optic vesicle. It is composed of hexagonal cells, from .012–.018 mm. in diameter, the protoplasm of which is loaded with fine, needle-shaped crystals of pigment (*fuscin*). The outer portion of the cells is almost free from pigment and contains the nucleus. From the inner border fine protoplasmic processes extend inward between the rods and cones of the neuroepithelial layer. Under the influence of light, the pigment particles wander into these processes and, under such conditions, the pigmented cells may remain attached to the retina when the latter is separated from the choroid. Ordinarily, the pigmented layer adheres to the choroid and, hence, was formerly considered to be a part of that membrane. The pigmented cells are separated by a distinct intercellular cement substance and in some of the lower animals contain colored oil droplets and particles of a highly refracting myelin-like substance (*myeloid granules* of Kühne).

FIG. 1219.



Pigmented cells from outer layer of retina; surface view. × 250.

The **layer of rods and cones**, although usually described as a distinct stratum, is only the highly specialized outer zone of the layer of visual cells and, therefore, constitutes the outer portion of the neuroepithelial division of the retina. It is composed, as its name indicates, of two elements, the *rods* and the *cones*, which are the outer ends of the rod and cone visual cells. They are closely set, with their long axes perpendicular to the surface of the retina. The rods far outnumber the cones, except in the fovea centralis, in which location cones alone are found. In the macula each cone is surrounded by a layer of rods; elsewhere the cones are separated by intervals occupied by three or four rods.

The *rods* of the human retina (Fig. 1221) have an elongated, cylindrical form, and measure approximately .060 mm. in length and .002 mm. in diameter. Each rod

is composed of an *outer* and an *inner segment*, of about equal length. The outer segment possesses a uniform diameter, is doubly refracting, and readily breaks up into minute disks. It is invested with a delicate covering of neurokeratin, contains *myeloid* (Kühne) and is the situation of the *visual purple* or *rhodopsin*. The inner rod segment is somewhat thicker and has an ellipsoidal form. It is singly refracting, homogeneous in structure (rapidly becoming granular after death) and from its inner extremity sends the delicate *rod-fibre* through the external limiting membrane into the outer nuclear layer where the nucleus of the rod visual cell is found.

The *cone visual cell* is composed of the same general divisions as the rod-cell, including the specialized outer part, the cone, and the body within the external nuclear layer. The *cones* are shorter than the rods, and, except in the fovea, have a length of .035 mm. Each one (Fig. 1221) is composed of an outer narrow cone-shaped segment, and an inner broader segment, which is distinctly ellipsoidal in form, with a diameter of .007 mm. The inner segment is double the length of the outer, and is continued inward as the *cone-fibre* with its nucleus in the outer nuclear layer. In the fovea, where the cones alone are found, they are of approximately the same length as the rods, and possess about one half the usual diameter.

FIG. 1220.

Section of human retina from near posterior pole. × 230.

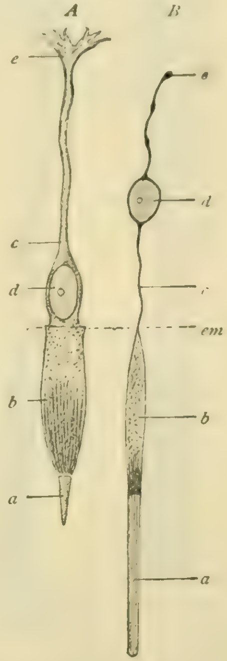
The **outer nuclear layer**, the inner portion of the neuroepithelial layer, is composed of the bodies of the rod and cone visual cells, which show chiefly as the nuclei, the so-called *rod-* and *cone-granules*. The *rod-granules* occupy an elliptical enlargement of the attenuated rod-fibres. They exhibit a transverse striation and are placed at varying levels within the layer. The rod-fibres are continued as a thin protoplasmic process into the outer reticular layer, where they form small end-knobs which are associated with the outer terminals of the small nerve-cells, the rod-bipolars. The *cone-granules* are less numerous than those of the rods, display no transverse markings, and are found only in the outer portion of the nuclear layer, near the external limiting membrane. The *cone-fibres*, the attenuated bodies of the cone visual cells, are broader than the corresponding parts of the rods and are continued through the outer nuclear layer as far as the outer portion of the external plexiform layer, where they end with a broad base, from which delicate processes extend inward to interlace with the terminal arborizations of the cone-bipolars. The outer nuclear layer is about .05 mm. in thickness.

The **outer plexiform layer** is a narrow granular looking stratum, between the outer and the inner nuclear layer, and constitutes the first of the cerebral layers of the retina. It is composed of the dendritic arborizations of the bipolar nerve-cells of the succeeding layer, which lie in close relation with the centrally directed processes from the foot-plates of the cone-cells and with the end-knobs of the rod-fibres. In addition to these constituents of the plexiform layer, numerous fibres arising from the protoplasmic processes of the horizontal cells of the inner nuclear layer also take part in its formation.

The **inner nuclear layer,** the most complicated of the retinal strata, measures .035 mm. in thickness near the optic disc. It contains nervous elements of three main types—the *horizontal cells*, the *bipolar cells*, and the *amacrine cells*—and, associated with these, the nuclei of the *sustentacular cells*.

The *horizontal cells* form the external layer, and were formerly included in the outer plexiform layer. They have flattened cell-bodies and send out from five to seven dendrites, which divide into innumerable branches and, passing into the outer plexiform layer, terminate in close association with the bases of the rod and cone visual cells. Each horizontal cell possesses also an axone, which is directed outward through the outer plexiform layer, and ends in a richly branched arborization about the visual cells. A second type of large horizontal cells is also described, some of which send axis-cylinder processes through the inner nuclear layer to form terminal arborizations in the inner plexiform layer. The function of the horizontal cells is not well understood, but they probably serve as association fibres between the visual cells.

FIG. 1221.



Visual cells from human retina, *A*, cone-cell; *B*, rod-cell; *a*, *b*, outer and inner segments; *c*, attenuated bodies (fibres), with nucleus (*d*) and central ends (*e*); *em*, position of external limiting membrane. × 750. (*Greeff.*)

The *bipolar cells*, the ganglion cells of this layer, are of two chief varieties, the *rod-bipolars* and the *cone-bipolars*. They are oval cells, each sending an axone inward toward the inner plexiform layer, which ends in communication with the large nerve-cells of the ganglion cell layer, and a dendrite outward which is associated with the end terminals of the visual cells and with the arborizations of the horizontal cells. The dendrites of the rod-bipolars form an arborescence of vertical fibrils, which enclose from three to twenty end knobs of the rod-fibres, whilst their axis-cylinders pass entirely through the inner plexiform layer and usually embrace the cell-body of one of the large ganglion cells. The dendrites of the cone-bipolars, on the other hand, bear horizontal arborizations which interlace with the fibrils from the foot-plates of the cone-cells. Their axones penetrate less deeply into the inner plexiform layer than do those of the rod-bipolars, coming in contact at various levels with the peripherally directed dendrites of the ganglion cells.

The *amacrine cells* are placed in the inner portion of the nuclear layer. Formerly considered as sustentacular elements, they are now recognized as nerve-cells, although, as their name indicates, no distinct axone can be demonstrated. They possess, however, richly branched dendritic processes, which ramify in the inner plexiform layer and end either as the brush-like arborizations of the *diffuse amacrines*, or as the horizontally branching arborizations of the *stratiform amacrines*. A third type, known as *association amacrines*, is also described. They connect widely separated amacrine cells of the same layer (Cajal).

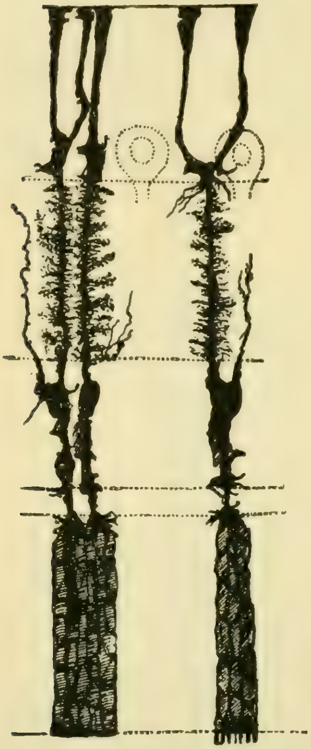
The nuclei of the sustentacular cells, the fibres of Müller, will be described later (page 1466).

The **inner plexiform layer,** .04 mm. in thickness, appears granular, similar to the corresponding outer zone, and is composed of the interlacing axones of the bipolar, amacrine and horizontal cells from the inner nuclear layer and the dendrites of the large ganglion cells in the subjacent retinal layer. Intermingled with them are also the fibres of Müller, which form conspicuous vertical striæ, with lateral offshoots within the stratum.

The **layer of ganglion cells,** consists, throughout the greater part of the retina, of a single row of large multipolar neurones, each with a cell-body containing a vesicular nucleus and nucleolus and showing, like many other ganglion cells of the central nervous system, typical Nissl bodies and a fibrillar structure. Near the macular region, the ganglion cells are smaller but more numerous and arranged as several superimposed layers; toward the ora serrata, on the contrary, the individual

cells are separated by considerable intervals. Their axones, or axis-cylinder processes, pass inward and become the nerve-fibres of the fibre layer. Converging toward the optic entrance, they become consolidated into the optic nerve and pass to the brain. The dendrites of the ganglion cells, one to three in number, run outward into the inner plexiform layer and end as richly branched arborizations. These, like those of the amacrine cells, terminate either diffusely, or in horizontal ramifications limited to definite strata, in connection with the centrally directed processes from the bipolar cells.

Fig. 1222.



Supporting fibres of Müller from retina of ox; Golgi preparation. (*Cajal.*)

The **nerve-fibre layer** is composed almost entirely, but not exclusively, of the axones of the ganglion cells of the preceding layer. The individual fibres, from .005–.05 mm. in diameter, are collected into bundles of varying size, which take a horizontal course and converge toward the optic disc. They are normally devoid of medullary sheaths, but acquire them after passing through the lamina cribrosa of the sclera. A few of the fibres are *centrifugal*, arising from ganglion cells within the brain, and terminate apparently in connection with the association amacrines of the inner nuclear layer.

In the macular region, the nerve-fibres are practically absent, those from the retinal area lying directly to the temporal side of the macula arching above and below the yellow spot. From the macula itself, a special strand, known as the *maculo-papillary bundle* and composed of about twenty-five fasciculi, passes directly to the nerve-disc.

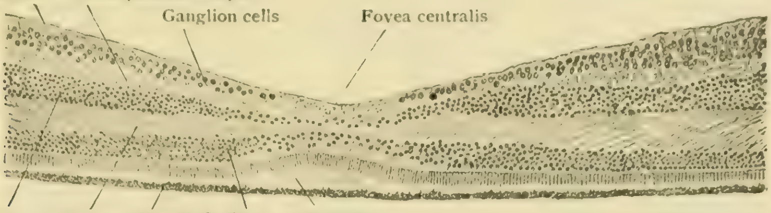
The **sustentacular tissue,** the neuroglia of the retina, exists in two forms—as the *fibres of Müller* and as the *spider cells.*

The **fibres of Müller** are modified neuroglia fibres which pass vertically from the inner surface of the retina through the succeeding layers as far as the bases of the rods and cones (Fig. 1222). The inner extremities of the fibres possess conical expansions, which are in apposition and form an incomplete sheet, known as the *membrana limitans interna.* As the fibres traverse the retinal layers, they give off delicate lateral offshoots, which break up into a fine supporting reticulum. Within the inner nuclear layer each fibre presents a broad expansion, in which is situated the oval nucleus of the sustentacular cell, the fibre of Müller. After traversing the outer nuclear layer their broadened peripheral ends come into contact and form a continuous sheet, the *membrana limitans externa.* From the latter delicate offshoots continue outward and embrace the bases of the individual rods and cones. In addition to the robust fibres of Müller, neuroglia cells, in the form of *spider cells*, are found in the nerve-fibre and ganglion cell layers. These cells send out long delicate processes which extend between the processes and cells and thus help to support them.

The Macula Lutea.—The structure of the retina undergoes important modifications in two areas, at the macula lutea and at the ora serrata. In the former the ganglion cells increase rapidly in number as the macula is reached, so that instead of forming a single layer they are distributed in from eight to ten strata. The inner nuclear layer is also increased in thickness. Within the **fovea centralis,** however, in order to reduce to a minimum the layers traversed by the light-rays, the cerebral layers are almost entirely displaced, only the absolutely essential retinal strata—the pigment cells and the visual cells with their necessary connections—being retained within the area of sharpest vision (Fig. 1223). On approaching the fovea, the ganglion cells rapidly decrease in number, until at the centre of the depression, they are entirely absent and the nerve-fibre layer, therefore, disappears. The bipolar

cells are present as an irregular layer within the fused remains of the two plexiform layers. The most conspicuous elements are the visual cells, which in this position are represented solely by the cones, which have about twice their usual length and thickness, the increase in length being contributed by the outer segments. The cone-cell nuclei become removed from the external limiting membrane; the cone-fibres are therefore lengthened, pursue a radial direction, and constitute the so-called

FIG. 1223.

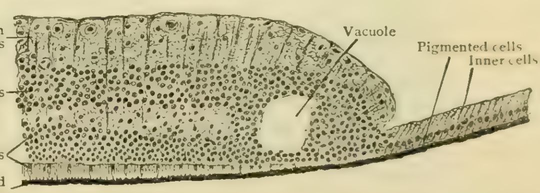


Section of human retina through fovea centralis. × 80.

fibre-layer of Henle. Opposite the centre of the fovea, the choroid is thickened by an increase in the choriocapillaris. The yellow color of the macula is due to a diffuse coloration of the inner retinal layers.

The Ora Serrata.—The visual part of the retina ends anteriorly in an irregular line, the ora serrata. Within a zone of about 1 mm. in width, the retina diminishes in thickness from .50 to .15 mm., in consequence of the abrupt disappearance of its nervous elements. The rods disappear first; then the cones become rudimentary, and finally cease; the ganglion cells, nerve-fibre layer and inner plexiform layer fuse, and the two nuclear layers unite and lose their characteristics, most of the nuclei present being those of the supporting fibres of Müller, which are here highly developed. These elements continue beyond the ora serrata (Fig. 1224) as the transparent cylindrical cells composing the inner layer of the *pars ciliaris retinæ*, the densely pigmented cells of the outer layer being a direct continuation of the retinal pigmented cells. These two strata of cells are prolonged over the ciliary body and the iris as far as the pupillary margin, over the iris constituting the *pars iridica retinæ*. As the columnar cells pass forward, they gradually decrease in height, and at the junction of the ciliary body and the iris the cells of both layers become deeply pigmented, with consequent masking of the boundaries of the individual elements. The cells of the anterior layer are of additional interest as giving rise to the dilatator muscle of the iris.

FIG. 1224.



Section of human retina through ora serrata, showing transition of pars optica into pars ciliaris. × 165

The aggregation incident to the convergence of the nerve-fibres from all parts of the retina produces a marked thickening of the fibre-layer around the optic disc, and as the fibres turn outward to form the optic nerve the other layers of the retina, together with those of the choroid, suddenly cease. On the temporal side a narrow meshwork of *intermediate tissue* separates the nerve-fibres from the other retinal strata, but at the nasal side this tissue is absent. The ganglion cells disappear first, whilst the pigmented cells, with the lamina vitrea of the choroid, extend furthest inward.

The **blood-vessels** of the retina are derived from a single artery, the *arteria centralis retinæ*, which enters the optic nerve at a point from 15–20 mm. behind the eyeball, and, with its accompanying vein, runs in the axis of the nerve and

emerges slightly to the nasal side of the centre of the optic disc. Here the artery divides into two main stems (Fig. 1225), the *superior* and *inferior papillary branches*, each of which subdivides at or near the disc-margin into superior and inferior *nasal* and *temporal branches* which run respectively mesially and laterally, dividing dichotomously as *end arteries*, no anastomosis existing. The macular region is supplied by special *macular branches*, the center of the fovea, however, being free from blood-vessels. The larger branches from the central artery course within the nerve-fibre layer, and send fine twigs directed peripherally to form an *inner* and an *outer plexus*, the former on the outer surface of the inner plexiform layer, and the latter within the inner nuclear layer. Beyond the outer plexiform layer the vessels do not penetrate, the visual cells being dependent for their nourishment upon the choriocapillaris of the choroid. At the nerve entrance an indirect communication exists between the arteria centralis and the posterior ciliary arteries, through the medium of the small branches which constitute the *circulus arteriosus Zinni.*

FIG. 1225.

Normal fundus of right eye as seen with ophthalmoscope; central retinal vessels seen emerging from optic nerve; arteries are lighter, veins darker vessels; fovea centralis shows as light point in macular region, which lies in temporal field and is devoid of large vessels.

The **lymphatics** of the retina are represented chiefly by the perivascular lymphatic spaces which surround all the veins and capillary blood-vessels. These spaces may be injected from the subpial lymph-space of the optic nerve, and by the same method communications may be demonstrated between (1) this space and the interstices between the nerve bundles which converge toward the optic papilla, (2) a space between the membrana limitans interna and the hyaloid membrane of the vitreous, and (3) a narrow cleft between the pigmented cells and the layer of rods and cones.

Practical Considerations.—All pathological conditions of the retina appear as opacities, and thus interfere with sight. The medullary sheaths of the optic nerve-fibres end at the lamina cribrosa. Rarely the sheaths around these may extend some distance into the retina, showing as a white striated margin around the optic disc and continuous with it. Sometimes the blood-vessels of the retina may enter at the margins of the optic disc, instead of at its centre, as usual, which is then free of vessels and very pale. At the entrance of the optic nerve, the transparency of the retina is lessened by the thickening of its fibre-layer

The integrity of the *central artery* of the retina is necessary to the preservation of sight. The branches of this vessel are distributed to the retina only, and have no communication with those of the other coats, nor do they anastomose with one another. If the main artery or one of its branches is plugged with an embolus, the area supplied by the blocked vessel is then deprived of sight.

The retina may undergo inflammatory change in nephritis, syphilis, diabetes, and other constitutional diseases. Of all these inflammations of the retina, that due to kidney disease (albuminuric retinitis) is the most characteristic. Besides the signs of general inflammation, as haziness of the retina, choked disc, distended retinal arteries, or hemorrhages into the retina, pure white or even silvery patches often occur; they are due to fatty degeneration. Retinitis without these characteristic changes may occur from albuminuria, so that the urine should be examined in all cases of retinitis.

The retina between the optic nerve and the ora serrata is held in apposition to the choroid only by the support afforded by the vitreous body. It may be readily detached from the choroid by such causes as injury, extravasation of blood or serum between the two layers, or by tumors of the choroid.

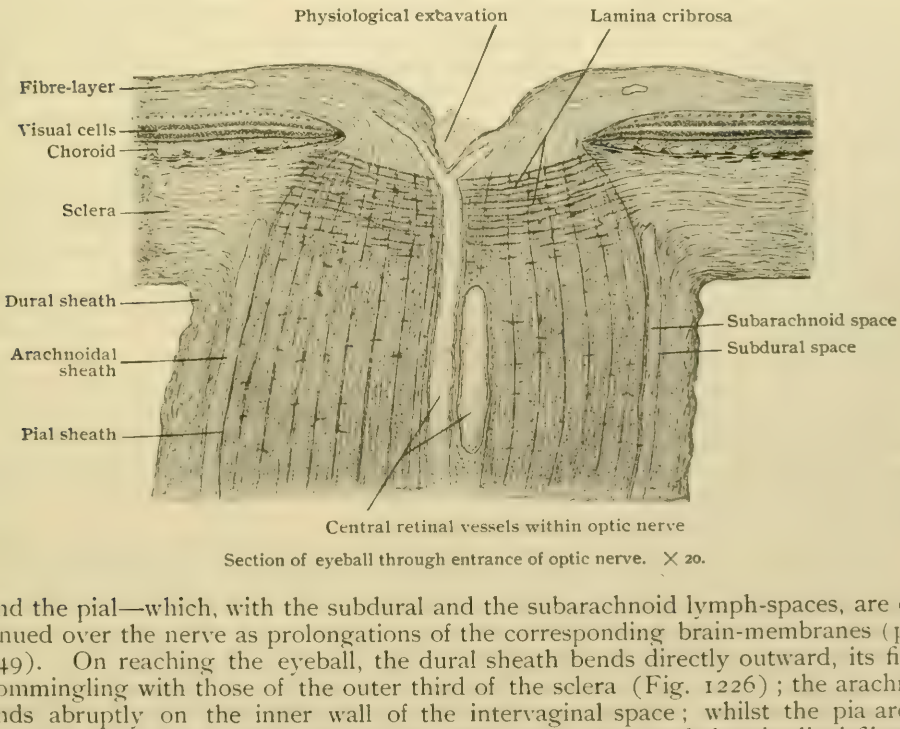
In contusions of the eye the retina is sometimes torn alone, although this is rare. The retina does not tear as easily as the choroid, as is shown by the fact that in ruptures of the choroid the retina is generally not lacerated.

Glioma is the only tumor found in the retina, and occurs exclusively in children, usually under three years of age.

A rare tumor arising from the pars ciliaris retinæ has been described, to which the name *terato-neuroma* has been applied by Verhoeff.

The Optic Nerve.—The extraocular portion of the optic nerve has been described elsewhere (page 1223). Likewise, the three sheaths—the dural, the arachnoid

FIG. 1226.

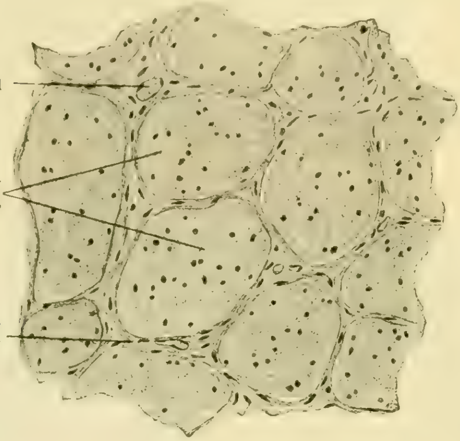


Section of eyeball through entrance of optic nerve. × 20.

and the pial—which, with the subdural and the subarachnoid lymph-spaces, are continued over the nerve as prolongations of the corresponding brain-membranes (page 949). On reaching the eyeball, the dural sheath bends directly outward, its fibres commingling with those of the outer third of the sclera (Fig. 1226); the arachnoid ends abruptly on the inner wall of the intervaginal space; whilst the pia arches outward to form part of the inner third of the sclera, but sends longitudinal fibres as far as the choroid. As the nerve-fibres enter the eyeball, for convenience assuming that they are passing from the brain toward the retina, they traverse a fenestrated

membrane, the **lamina cribrosa,** which is formed by interlacing bundles from the inner third of the sclera and from the pial sheath. As they penetrate the lamina cribrosa they lose their medullary sheaths; in consequence the optic nerve is reduced one third in diameter. The intervaginal lymph-space ends abruptly, being separated from the choroid by the fibres of the pia which arch outward to join the sclera. The nerve projects slightly into the eyeball on account of the thickness of the layer of arching nerve-fibres and forms, therefore, a circular elevation, known as the **optic papilla** or **optic disc,** about 1.5 mm. in diameter, the center of which is occupied by a funnel-shaped depression, the so-called *physiological excavation.* The axis of the nerve is occupied by the central artery of the retina, which gives off minute branches for the nutrition of the nerve, that anastomose with the pial vessels, and, through the circulus arteriosus Zinni, with branches of the posterior ciliary arteries. When seen in transverse sections (Fig. 1227), the optic nerve appears as a mosaic of irregular polygonal areas composed of bundles of medullated nerve-fibres surrounded by connective tissue envelopes. Although provided with medullary sheaths, the optic fibres are devoid of a neurilemma, in this respect agreeing with the nerve-fibres composing the central nervous system. The entire nerve corresponds to a huge funiculus, the perineurium being represented by the pial sheath, and the endoneurium by the interfascicular septa of connective tissue prolonged from the pia between the bundles of fibres. Numerous connective tissue cells occur along the strands of fibrous tissue.

FIG. 1227.



Transverse section of part of optic nerve, showing several fasciculi of nerve-fibres. × 125.

Practical Considerations. Any disturbance of the optic nerve-fibres passing from the retina to the cortex of the brain (page 1225) will cause disturbance of vision, and within certain limits the lesion may be localized by the character of the symptoms produced.

The most characteristic symptom from a lesion on one side behind the chiasm is a *homonymous lateral hemianopsia,*—that is, the right or the left half of each eye will be blind. This is explained by the fact that the optic tracts are made up of fibres coming from the corresponding lateral halves of both retinæ,—*i.e.*, the fibres from the right half of each retina pass to and make up the right optic tract, and pass therefore to the right half of the brain. It will thus be seen that anything compressing the optic fibres of the right side behind the chiasm, for instance a hemorrhage, would produce a blindness—more or less complete according to the extent of the fibres involved—of the right half of each eye.

Since most of the optic fibres enter the lateral geniculate bodies, a lesion there always causes hemianopsia, or half-eye blindness. Lesions of the optic thalamus, or of the superior quadrigeminal body, may also by compression of the adjacent optic tract produce hemianopsia.

In the *optic radiation* are other than optic fibres, so that hemianopsia may or may not follow lesions in that tract, according to whether optic fibres are involved or not. The exact course of the visual fibres in the optic radiation is uncertain. If the visual area of the brain cortex is involved by the lesions, no other symptoms will be present, but the hemianopsia will be complete and homonymous—that is, the corresponding halves of the two eyes will be blind.

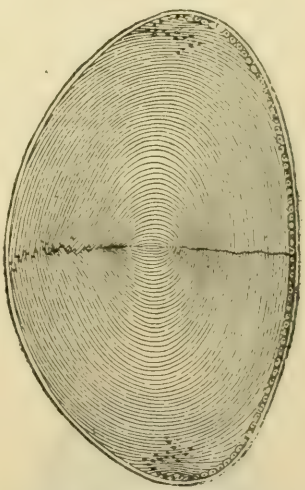
If the lesion affect the *chiasm*, as from tumors of the pituitary body, periostitis of the body of the sphenoid bone, tuberculous or syphilitic exudate, causing pressure on the mesial portion of the chiasm involving the decussating fibres, the nasal half of each eye supplied by these fibres will be blind (heteronymous hemianopsia). Since the nasal half of each eye perceives the temporal half of the visual field, this variety of half-blindness is called *bitemporal hemianopsia*.

If the *optic fibres* of one side in front of the chiasm are involved, the disturbance of vision will affect one eye only, so that the occurrence of absolute blindness of one eye, without other known cause, with good sight in the other, would suggest a lesion in front of the chiasm.

Inflammation of the intraocular end of the optic nerve—that is, of the *optic disc*, or *papilla*—gives rise to the condition to which the name *optic neuritis*, or *papillitis*, is applied, which is then recognizable with the ophthalmoscope. If in addition to or independently of the signs of inflammation there are marked engorgement, œdema, and the evidence of mechanical compression, so that the swollen nerve-head protrudes into the vitreous beyond ½ to ¾ mm., the phenomena of "choked disc" are present. This variety of papillitis, as well as more moderate grades of optic neuritis, constitutes one of the important symptoms of brain tumor, occurring in fully 80 per cent. of the cases. The development of the papillitis does not necessarily depend upon the size of the growth, nor upon its situation, except that tumors of the medulla are less apt to originate optic neuritis than those in other parts of the brain. Usually a bilateral condition, it is sometimes unilateral, and under such circumstances it suggests that the cerebrum is the seat of the growth, and is, on the whole, in favor of the tumor being on the same side as the neuritis. With this exception, however, optic neuritis, although an important symptom of brain tumor, has no localizing significance. Other intracranial causes of optic neuritis are the various types of meningitis (when the ophthalmoscopic picture often appears in the form of the so-called "descending neuritis"), abscess and softening of the brain, cerebritis, hydrocephalus and aneurism. In addition to the intracranial causes of papillitis, this phenomenon may arise from a general infection—for example, influenza, syphilis, rheumatism, small-pox, etc.—and is then known as *infectious optic neuritis*. It is also caused by various toxic agents, by anæmia, by menstrual disturbances, nephritis, and other constitutional disorders (de Schweinitz).

Injuries of the optic nerve are most frequently the result of fractures of the base of the skull at the optic foramen, the nerve being injured by the fragments. It may be wounded by foreign bodies entering the orbit, with or without injury of the eyeball.

FIG. 1228.



Meridional section of human lens and its capsule; anterior epithelium and transitional zone are seen. × 7. (*Babuchin.*)

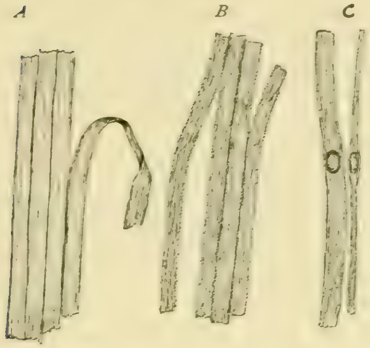
THE CRYSTALLINE LENS.

The lens, the most important part of the refractive apparatus of the eye, is a biconvex body situated on a level with the anterior plane of the ciliary body, from which it is suspended by the *suspensory ligament*, or *zonule of Zinn*. Its anterior surface supports the pupillary margin of the iris, and its posterior surface rests in a depression, the *patellar fossa*, on the anterior surface of the vitreous body. It is completely transparent and enclosed in a transparent elastic membrane, the *lens capsule*. Together with the capsule, the lens measures from 9–10 mm. in its transverse diameter, and about 4 mm. in thickness from pole to pole. The convexity of its two surfaces is not the same, that of the posterior being greater than that of the anterior. Neither are these convexities constant, since they are continually changing with the variations in lens-power incident to viewing distant or near objects. The radius of curvature of the anterior surface is approximately 9 mm. and that of the posterior surface 6 mm. when the eye is accommodated

for distant objects; these radii are reduced to about 6 and 5 mm. respectively in accommodation for near objects. The anterior surface is therefore more affected in the act of accommodation, the lens becomes more convex and its antero-posterior diameter increases from 4 to 4.4 mm. The superficial portion of the lens beneath the capsule is composed of soft compressible material, the *substantia corticalis;* the consistency gradually increases toward the centre, especially in later life, so that the central portion, the *nucleus lentis*, is much firmer and dryer.

The **structure** of the lens includes the capsule and its epithelium and the lens substance. The **capsule**, which entirely surrounds the lens, is a transparent, structureless, highly elastic membrane, which, while resistant to chemical reagents, cuts easily and then rolls outward. It is thickest on the anterior surface, where it measures from .010–.015 mm., and thinnest at the posterior pole (.005–.007 mm.). In the adult the lens is devoid of blood-vessels, but during a part of fœtal life it is surrounded by a vascular net-work, the *tunica vasculosa lentis*, which is supplied chiefly by the hyaloid artery. This temporary vessel is the terminal branch of the central artery of the retina and passes from the optic disc forward through the *hyaloid canal* or *canal of Cloquet* in the vitreous to the posterior surface of the lens. The vascular lens tunic and the hyaloid artery are temporary structures and usually disappear before birth. Exceptionally they may persist, the tunic being represented by the pupillary membrane and the artery by a fibrous strand within the vitreous, stretching from the optic disc towards the lens. The capsule probably represents an exudation product of the cuticular elements from which the lens-substance is developed.

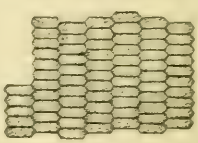
FIG. 1229.



Fragments of isolated lens-fibres; *A*, from superficial layers; *B*, from deeper layers; *C*, young fibres with nuclei. × 275.

The anterior portion of the capsule is lined by a single layer of flat polygonal cells, the *epithelium of the lens capsule*, which represents morphologically the anterior wall of the original lens-vesicle (page 1481). On approaching the equator of the lens, these cells become elongated, and gradually converted into the young lens-fibres, the nuclei of which form a curved line, with its convexity forward, in the superficial part of the lens.

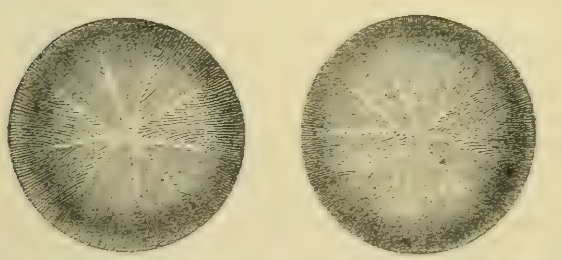
FIG. 1230.



Lens-fibres seen in transverse section. × 280.

The **lens-substance** is composed of long flattened fibres, the cross-sections of which have a compressed hexagonal outline, from .005–.011 mm. broad and from .002–.004 mm. thick, held together by an interfibrillar cement substance. These fibres are modified epithelial elements, which develop by the elongation of the original ectoblastic cells of the posterior layer of the lens-vesicle. The subsequent growth of the lens depends upon a similar modification of the anterior capsule-cells, the region where this transformation occurs being known as the *transitional zone*. The individual lens-fibres vary greatly in length, those forming the outer layers being longer and thicker than those which constitute the nucleus of the lens. The edges of the fibres are finely serrated, and, as the points of the serrations of adjacent fibres are in contact, fine intercellular channels are left for the

FIG. 1231.



Adult crystalline lens, showing lens-stars; *A*, anterior; *B*, posterior surface; radiating lines of juncture meet at central area. × 4. (*Arnold.*)

passage of nutritive fluid. The fibres are so arranged that their ends terminate along definite radiating striæ, or *lens-stars*, which in the young lens are three in number on each surface. In the adult lens additional rays increase the number to from six to nine, the striæ being less distinct but distinguishable with the ophthalmoscope. The lens-fibres which come from the pole of one surface of the lens terminate at the end of one of the radial striæ in the other, and conversely; the intervening fibres take up intermediate positions. In adult life the lens-fibres become more condensed, the lens loses its clear appearance, and assumes a yellowish tint. This change affects the nucleus first and the periphery later, coincidently the lens becoming less elastic as the result of its loss of water.

Practical Considerations.—The lens may be congenitally absent (aphakia), or it may be abnormal in size, shape, position, or transparency. Its anterior or posterior surface may be abnormally convex (lenticonus). Congenital anomalies of position (ectopia lentis) occur rarely. The lens may remain in its fœtal position in the vitreous chamber, or it may be displaced in an equatorial direction from faulty development and weakness of some part of the suspensory ligament. This weakness usually occurs below so that the lens moves upward. The ligament may be absent in its whole circumference, when the lens may be protruded into the anterior chamber.

Coloboma or partial deficiency of the lens is very rare. It is with comparative frequency associated with a similar defect in the iris, ciliary body and choroid, and, like it, is usually in the lower portion. A defect of the corresponding part of the suspensory ligament is occasionally present.

Traumatic luxation of the lens may take place into the vitreous or aqueous chamber. It may occur laterally through the coats of the eyeball into the capsule of Tenon or under the conjunctiva. That into the vitreous is most frequent.

The *capsule* of the lens is strong and elastic. It is at the same time brittle, breaking like thin glass when torn as by a sharp instrument. For this reason it is sometimes called the vitreous membrane. The anterior layer of the capsule is considerably thicker than the posterior, and is more liable to pathological changes, producing opacities. Wounds of the capsule permit the aqueous fluid to reach the lens fibres, which then become swollen, opaque, and finally disappear from the dissolving action of the aqueous. Advantage of this is taken in the needling operation (discission) for the removal of a cataract.

In children the lens substance is of nearly equal consistency throughout, but as age advances the central portion becomes gradually more condensed, and is called the nucleus. A well-marked nucleus, however, does not exist until adult life. In old age the lens loses its elasticity so that the changes necessary for accommodation are interfered with, and sight is disturbed. The hardened nucleus permits a greater reflection of light than the outer portion, so that the lens is more readily seen in older people, and the pupil loses more or less its blackness.

A *cataract* is an opacity of the lens, or its capsule, but that of the lens is so much more common than that of the capsule, that by the word cataract the lenticular is usually meant, unless the word is otherwise qualified. All cataracts are at sometime partial, and they are called according to their location, anterior polar or capsular, posterior polar or capsular, central or nuclear, lamellar, perinuclear and cortical. Cataract occurs sometimes in the young, and is then soft; that is, the lens has no nucleus.

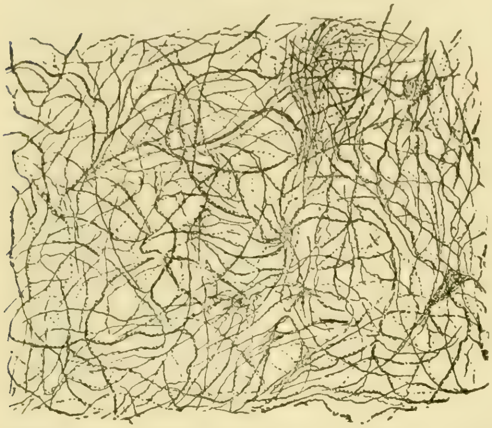
The Vitreous Body.

The vitreous body (**corpus vitreum**) fills the space between the lens and the retina, being in close contact with the retina and acting as a support to it as far forward as the ora serrata. Here it becomes separated from the retina and passes to the posterior surface of the lens, presenting a shallow depression, the **fossa hyaloidea** or *patellar fossa*, on its anterior surface for the reception of the lens. The fresh vitreous is a semifluid, perfectly transparent mass which consists of about 98.5 per cent. of water.

The **structure** of the vitreous has been a subject of protracted dispute, but recent investigations have established beyond question that it possesses a framework,

composed of delicate, apparently unbranched fibrils, which pass in all directions through the vitreous space and form the meshes in which the fluid constituents of the mass are held. The surface of the vitreous is enclosed by a delicate boundary layer, called the **hyaloid membrane,** formed by condensations of the fibrils, which are here arranged parallel to the surface, and closely felted. It is, however, not a true membrane, but only a condensation of the vitreous fibres. The vitreous is attached firmly to the retina at the nerve entrance and at the ora serrata, between these points the hyaloid being indistinct. As the vitreous leaves the retina, the boundary layer becomes thicker, in some cases to become thin again or absent in the region of the patellar fossa.

FIG. 1232.



Portion of adult vitreous body, showing felt-work of fibres and atrophic traces of cells. × 450. (*Retzius.*)

The central part of the vitreous is occupied by a channel, the **hyaloid canal,** also known as the *canal of Stilling* or the *canal of Cloquet,* which is about one millimeter wide and extends from the optic entrance toward the posterior pole of the lens. During fœtal life this canal lodges the *arteria hyaloidea,* the continuation of the central artery of the retina, which passes to the lens and assists in forming the embryonal vascular envelope surrounding the lens. Usually the embryonal connective tissue, together with the blood-vessel, disappears; occasionally, however, delicate remnants of this tissue can be detected.

The normal adult vitreous ordinarily contains no cells, but some are occasionally seen near the surface, beneath or on the hyaloid membrane. They are amœboid, often contain vacuoles and are to be considered as modified leucocytes. In addition a few branched connective-tissue cells may be present.

Practical Considerations.—Congential abnormalities of the vitreous are due either to a persistence of some part of its fœtal vascular apparatus or to an atypical development of the tissue from which it is formed. The remains of these structures may occasionally be seen as a filamentous band, free at one end, which floats in the vitreous, the other end being attached to the optic disc behind, or the posterior surface of the lens in front. The strand may be attached at both ends, with or without a patent artery. Small rounded gray bodies, apparently cystic and attached to the disc, are occasionally seen. They are in some way the remains of the fœtal vascular apparatus. The congenital opacities sometimes seen at the posterior pole of the lens are probably derived from the posterior fibro-vascular sheath of the lens. Materials from the blood are readily absorbed by the vitreous, as the bile in jaundice.

Muscæ volitantes are the flocculi, seen by the patient as black spots before the eyes, and are sometimes made up of inflammatory exudate from inflammation of the internal or middle coat of the eye. They may be due to blood from traumatic or spontaneous hemorrhage into the vitreous. Muscæ volitantes are often seen independently of any vitreous disease and are due to the shadows thrown upon the retina by naturally formed elements in the vitreous body, perhaps the remains of embryonic tissue. Some of the vitreous may be lost and rapidly replaced without seriously disturbing sight. In the removal of cataract, the suspensory ligament may be divided and an embarrassing loss of vitreous may result.

A *foreign body* in the vitreous chamber generally gives rise to a serious inflammation, which may destroy the eye. If loose, it tends by gravity to settle in the lower portion, and usually rests on the posterior part of the ciliary body (T. Collins). Rarely, in the absence of infection, it has remained for years without setting up inflammation. The rule is, however, to remove them, when recent, as early as possible, as inflammation may set in at any time. In most cases the foreign body

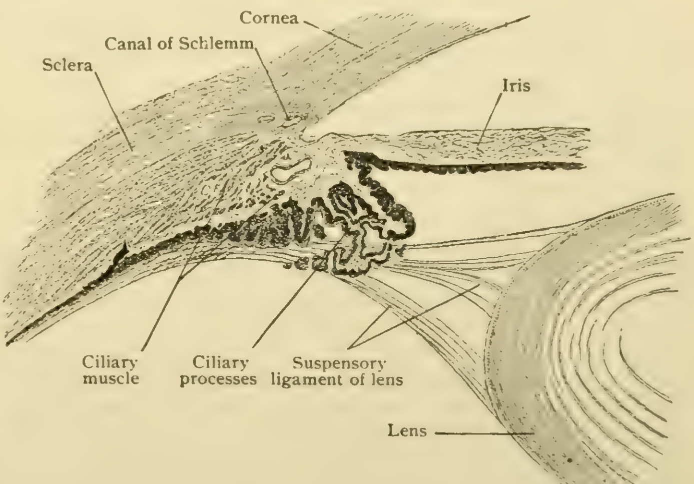
can be exactly localized by the X-ray, and if of iron or steel, may often be removed by a magnet. The accident is always serious and may be followed by a virulent inflammation, demanding an excision of the globe to prevent a sympathetic involvement of the other eye. Because of the risk of infection and loss of fluid, operative interference in the vitreous chamber is usually to be avoided.

Sympathetic ophthalmitis, or more accurately, *infective irido-cyclitis*, or *uveitis*, is an inflammation of one eye, usually called the "*sympathizer*," owing to injury or disease of the fellow eye, usually called the "*exciter*." Traumatisms of the ciliary region (danger zone) which have set up an irido-cyclitis or uveitis are responsible for fully 80 per cent. of the cases of so-called sympathetic inflammation. This disease was formerly supposed to be due to reflex action through the ciliary nerves, and this theory in a modified form is still maintained by a few clinicians. The "*migration theory*" propounded by Leber and Deutschmann that the inflammation is a progressive process in the continuity of the tissue of one eye to the other by way of the optic nerve apparatus and is of bacterial origin, has not been proved. It is believed by some investigators that the bacteria which enter the primarily affected eye produce a toxin which causes the disease, and by others that it represents an endogenous infection produced by invisible bacteria, that is, that it is a *metastasis* (de Schweinitz).

The Suspensory Apparatus of the Lens.

The lens is held in position by a series of delicate bands, which pass from the vicinity of the ora serrata over the ciliary processes to be attached to the periphery of the lens. These fibres collectively constitute the **suspensory ligament,** or **zonula of Zinn,** a structure of importance not only for the support of the lens but also in assisting the ciliary muscle in effecting the changes in the curvature of the lens incident to accommodation. The zonula is not, as formerly believed, a continuous membrane, but is composed of a complicated system of fibres. The latter, varying in thickness from .005–.022 mm., arise chiefly from the cuticular membrane covering the pars ciliaris retinæ in the vicinity of the ora serrata. The investigations of Retzius, Salzmann and others indicate that some fibres arise also from the membrana limitans interna of the *pars optica retinæ*, whilst others pass into and end within the vitreous body. The greater number of the fibres pass forward chiefly in the depressions between the ciliary processes, and along the sides of the latter, closely applied to the surface; they then proceed outward across the circumlental space to be attached to the capsule of the lens. Some of the fibres are inserted anterior to the equator, others posterior to the equator, and some directly into the lens margin. Those inserted anteriorly arise behind and chiefly from the valleys between the ciliary processes, whilst those inserted back of the equator come from the ciliary processes in front. As they diverge to gain their insertion in the lens-capsule, the crossing fibres enclose an annular space, triangular in section, whose base is directed toward

Fig. 1233.



Meridional section of ciliary region, showing ciliary processes and suspensory ligament of lens. × 20.

the lens equator. The fibres are so closely interlaced that it is possible to inject air between them and so produce a beaded ring surrounding the lens. This appearance was long interpreted as demonstrating the presence of a delicate channel, the *canal of Petit*, encircling the lens. The existence of a definite channel, however, is no longer accepted, the space capable of inflation being part of the larger circumlental space, which is filled with fluid and communicates, by means of fine clefts, with the posterior chamber.

In addition to the chief zonular fibres, accessory bands occur, some of which pass from the ciliary processes to the long zonular fibres, whilst others extend from point to point on the ciliary processes.

The origin of the vitreous body and of the suspensory ligament has long been and still is a matter of dispute. The fact that these structures are very closely connected, that fibres from the suspensory ligament pass through the vitreous, and, in some cases at least, end in that body, renders it probable that the two structures have a common genesis. Anatomists are divided, however, in their views, some believing the structures in question to be derived from the mesoblast which enters the choroidal cleft with the blood-vessels, whilst others assign to them an ectoblastic origin, the primary vitreous tissue being from the retina (inner wall of the secondary optic vesicle). In many of the lower animals the vitreous contains no blood-vessels, and, further, since the vitreous is formed without the presence of embryonal connective tissue, the presumption is strong that the vitreous arises from the retina. That the ectoblast in mammals, however, is the sole source of the vitreous has not been proven; moreover, the close histological resemblance of the vitreous to embryonal connective tissue suggests with much force the probability that the mesoblast has a considerable share in the formation of the vitreous body.

The Aqueous Humor and its Chamber.

The aqueous humor is the transparent fluid which fills the space between the anterior surface of the vitreous body and the posterior surface of the cornea. In chemical composition it closely resembles water, containing only traces of albumin and extractives, and differing from lymph in its low percentage of albumin. It is produced chiefly by the blood-vessels of the ciliary processes, the iris taking probably little or no part in the process. The albumin of the blood is separated by the action of the double layer of cells covering the pars ciliaris retinæ, which act either as a filtering medium (Leber), or as a secreting epithelium (Treacher Collins). The aqueous humor is constantly being produced and is carried off through the spaces of Fontana into the canal of Schlemm, and also through the lymph-spaces in the iris, its quantity being an important factor in determining intraocular tension. With the exception of a few migratory leucocytes, the aqueous humor is devoid of morphological elements.

The space occupied by the aqueous humor is incompletely subdivided by the iris into two compartments, the anterior and posterior chambers. The **anterior chamber** (**camera oculi anterior**) is bounded in front by the cornea, and behind by the iris and lens, and has a depth at its centre of from 7.5–8.5 mm. The **posterior chamber** (**camera oculi posterior**) is the small annular space, triangular in cross-section, which has for its anterior boundary the iris, and is limited laterally by the ciliary processes, and medially and posteriorly by the lens and the vitreous body. The spaces between the fibres of the suspensory ligament communicate with the posterior chamber, are filled with aqueous humor, and are, therefore, only a part of the posterior chamber.

Practical Considerations.—When the cornea is perforated as by a wound or by ulceration, the aqueous is forced through the opening so rapidly that the iris is swept along by it, and unless great care is observed it will become adherent to the margin of the corneal opening (anterior synechia).

The aqueous humor is of importance in the removal of foreign matter. Blood will often be removed in a few days. Suppuration of the adjacent tissue may lead to the collection of pus in the anterior chamber (hypopion). Hyphæmia is a collection of blood in this chamber, and of itself is not a grave condition, although it may be a sign of a more serious disease.

Glaucoma is a disease due to excessive intraocular tension which, unless relieved, progressively increases until the eye is destroyed, and which almost always involves the other eye. The abnormal tension is the result of disturbance in the outflow of the intraocular fluid. This fluid is an exudation from the blood-vessels of the ciliary body. From the posterior chamber the fluid passes through the pupil to the anterior chamber. It then escapes in the angle formed by the iris and cornea by passing through the lymph-spaces in the ligamentum pectinatum and by diffusion reaches the canal of Schlemm. Thence it passes out by the anterior ciliary veins. Obstruction in the path of this current occurs usually either in the lymph-channels of this region, or at the pupil from adhesion of the whole pupillary margin to the lens, or from occlusion of the pupil by inflammatory exudate, in iritis.

Iridectomy frequently gives relief in both varieties; in the former by opening up the lymph-spaces near the corneal angle of the anterior chamber, the incisions being carried well into this angle; in the latter by making a new opening for the current between the posterior and anterior chambers.

The symptoms, like the cause, may be explained largely upon an anatomical basis. The venæ vorticosæ pass obliquely through the sclerotic and are therefore compressed and obstructed by the distension. Their blood is then compelled to escape through the anterior ciliary veins, which penetrate the sclerotic more at a right angle, and are consequently distended. Œdema of the cornea results causing a superficial haziness. The cornea is insensitive from paralysis of the anterior ciliary nerves. Usually the anterior chamber is shallow because the lens and iris are pushed forward by the obstructed fluid behind, and the ciliary nerves being paralyzed the pupil is dilated and immobile, giving a staring expression. The optic disc is at first hyperæmic, and is consequently markedly depressed from the intraocular tension, giving rise to one of the most important symptoms, pathological *cupping of the disc*, or the *glaucomatous cup*. The great pain in glaucoma is due to compression of the sensory nerves of the ciliary body and iris against the unyielding sclera. The distended retinal veins can be seen through the ophthalmoscope.

A condition analogous to glaucoma, *hydrophthalmos*, occurs in children, and is either congenital or acquired very early in life. Unless relieved it almost always produces blindness.

THE LACHRYMAL APPARATUS.

The lachrymal apparatus consists of the gland secreting the tears, situated in the anterior and outer portion of the orbital cavity, and the system of canals by which the tears are conveyed from the mesial portion of the conjunctival sac to the inferior nasal meatus.

The **lachrymal gland** (**glandula lacrimalis**), resembling in shape and size a small almond, consists of two fairly distinct parts—the superior *orbital portion* and the inferior *palpebral* or *accessory portion*. The former occupies the fossa lacrimalis in the frontal bone and is the larger portion. It measures 20 mm. in length, 12 mm. in breadth and reaches from the edge of the superior palpebral muscle, along the upper margin of the orbit to the suture between the frontal and malar bones. The upper convex border is attached to the periosteum of the fossa by means of a number of bundles of connective tissue, which are inserted into its capsule. Below, it rests upon a fascial arch, which runs from the trochlea to the fronto-malar suture.

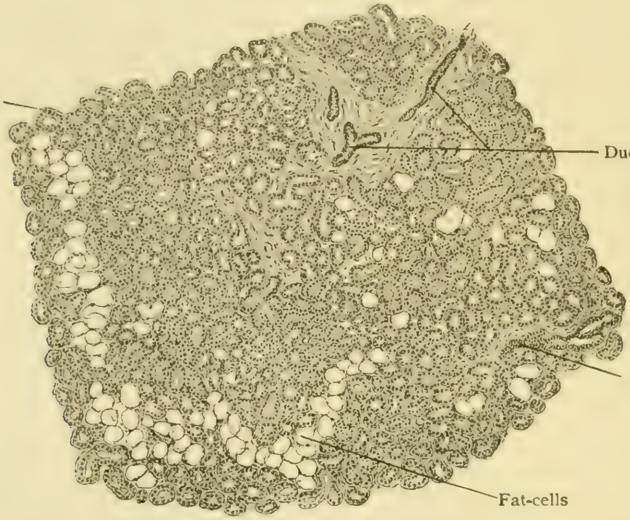
The lower or *palpebral portion* of the gland, *glandula lacrimalis inferior*, is somewhat smaller than the upper and separated from the latter by the fascial expansion already mentioned. Its lower concave surface rests upon the fornix of the conjunctiva, extending laterally almost to the outer canthus.

The **ducts** from both portions of the gland are exceedingly fine, those from the upper portion, from three to six in number, passing downward through the inferior portion. Some of the ducts from the lower gland join those coming from above; others run independently, in all about a dozen ducts opening into the conjunctival sac along a line just in front of the fornix. In **structure** the glands correspond to the tubo-alveolar type, and resemble the serous glands in their general character. The acini of the lower portion are separated by robust septa of connective tissue, which contain considerable lymphoid tissue.

The *arteries* of the gland are derived from the lachrymal, and the *veins* empty into the ophthalmic vein. The *nerves* include sensory fibres from the lachrymal branch of the ophthalmic, as well as secretory fibres from the sympathetic.

Accessory lachrymal glands are found in both the upper and lower fornices, from eight to thirty being present in the upper lid and from two to four in the lower. They are very small and situated chiefly near the outer angle of the palpebral fissure.

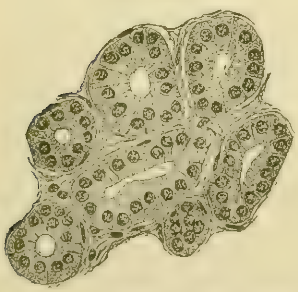
FIG. 1234.



Section of lachrymal gland, under low magnification, showing general arrangement of alveoli. × 20.

The **lachrymal passages** (Fig. 1236) begin by minute openings, the **lachrymal puncta,** which are usually placed at the summit of the conical **lachrymal papillæ.** The latter occupy the margins of the eyelids, near the mesial extremity, at a point where the arched palpebral borders pass over into the approximately horizontal boundaries of the lachrymal lake. The upper punctum is situated 6 mm. from the inner canthus; the lower one is slightly larger and a trifle farther removed from the canthus.

FIG. 1235.



Alveoli of lachrymal gland more highly magnified. × 235.

The puncta open into the **lachrymal canaliculi,** which at first are vertically directed, then bend abruptly mesially and, taking a nearly horizontal course parallel with the borders of the lachrymal lake, run as far as the inner canthus, where they empty usually by a common canal into the lateral and slightly posterior wall of the lachrymal sac. Occasionally the two canaliculi do not unite but open separately into a diverticulum of the sac, known as the *sinus of Maier.* Each canaliculus is from 8–10 mm. in length. The *lumen* of the canal measures only .1 mm. in diameter at the punctum, presents a diverticulum 1 mm. in diameter at the bend, and continues with an approximately uniform calibre of .5 mm. in its horizontal portion.

The **structure** of the canaliculi includes a lining of stratified squamous epithelium, which rests upon a delicate tunica propria rich in elastic fibres, muscular fibres from the orbicularis palpebrarum affording additional support. The muscle bundles run parallel to the horizontal portion of the canaliculi, but are arranged as a circular sphincter about the vertical portion.

The **lachrymal sac** (**saccus lacrimalis**) may be regarded as the upper dilated portion of the naso-lachrymal duct, the lower part of which passes through a bony canal and opens into the inferior nasal meatus beneath the lower turbinate bone,

The sac is about 15 mm. long, and 5–6 mm. in diameter when distended. It is situated near the inner canthus and lies within the deep lachrymal groove between the superior maxillary and the lachrymal bone. Its closed upper end, or *fundus*, extends beneath the internal tarsal ligament and some of the fibres of the orbicularis palpebrarum, whilst its orbital surface is covered by the fibres of the latter muscle, which spring from the lachrymal bone and are known as the *tensor tarsi* or *Horner's muscle*. The lower end of the sac narrows where it passes into the nasal duct. The wall is lined with a double layer of columnar epithelial cells, which in part are provided with cilia. It is composed of fibro-elastic tissue and is loosely connected with the periosteum.

The **nasal** or **naso-lachrymal duct**, the lower portion of the tear-passage, is situated within the bony canal formed by the superior maxillary, lachrymal and inferior turbinate bones. It varies in length from 12–24 mm., according to the position of the lower opening, and is from 3–4 mm. in diameter. Its direction is also subject to individual variation, but is slightly backward, as well as downward, and is usually indicated by a line drawn from the inner canthus to the anterior edge of the first upper molar tooth. The duct opens into the lower nasal meatus, at a point from 30–35 mm. behind the posterior margin of the anterior nares. The aperture may be imperfectly closed by a fold of mucous membrane, the so-called *valve of Hasner* (**plica lacrimalis**). The **structure** of the duct includes a lining of mucous membrane which is clothed with columnar epithelium and may contain glandular tissue in the lower portion. The mucous membrane is separated from the periosteum by areolar tissue and a venous plexus; it may present additional folds, resembling valves, the best marked of which is situated at the junction of the sac and the duct.

FIG. 1236.

Cast of tear-passages; *C*, canaliculi; *S*, lachrymal sac; *D*, naso-lachrymal duct; natural size. (*Dwight*.)

The *arteries* supplying the lachrymal duct are from the nasal and the inferior palpebral. The large and numerous *veins* mostly join the nasal plexus and empty into the ophthalmic and facial. The *nerves* are derived from the infratrochlear division of the nasal branch of the ophthalmic.

Practical Considerations.—The most frequent congenital error of development in the lachrymal apparatus is found in connection with the canaliculus. It may be entirely absent, or, what is more common, may appear only as a groove, the edges having failed to unite. This union of the edges may occur only in part, so that the canaliculus may have two or more openings.

The lachrymal gland is rarely the seat of inflammation. Hypertrophy or enlargement may be congenital or syphilitic. Prolapse or dislocation forward may occur so that the gland can be seen or felt below the upper outer margin of the orbit; it has been excised in extreme cases. Cysts are due to occlusion of one or more ducts.

The ducts of the gland open into the outer third of the upper conjunctival fornix, and the tears sweep over the front of the eye towards the puncta under the influence of gravity and the contractions of the orbicularis muscle. The lower punctum is frequently everted so that it no longer dips into the lacus lacrimalis, and the tears, instead of finding their way into the normal passage, flow over the lower lid on to the cheek (epiphora). This is usually the first step in the development of *ectropion* or turning out of the lid (*vide supra*). When the eversion cannot be corrected, the canaliculus is usually slit up on its posterior side so as to form a groove dipping into the lacus, from which the tears may again be taken up by the natural passages. The most common cause of epiphora is obstruction of the lachrymal passages. This occurs most frequently at the junction of the lachrymal sac and nasal duct, which is the narrowest part of the duct. The method of correcting such an obstruction is by the use of sounds, which are passed from the punctum with or without first slitting the canaliculus. The rule is to slit the canaliculus when the sounding is to be kept up for any length of time, but if it is performed for diagnosis only, the slitting is not done. The upper canaliculus is shorter but narrower than the lower,

which is usually selected, as there is less danger of laceration of the lining mucous membrane leading to narrowing or occlusion of the canaliculus by scar tissue.

Congenital fistulæ sometimes result from non-closure of the groove from which the sac and nasal duct are formed. The lachrymal sac is situated at the inner side of the inner canthus, behind the inner palpebral ligament, which is the best guide to it, and crosses about the junction of the upper and middle thirds of the sac.

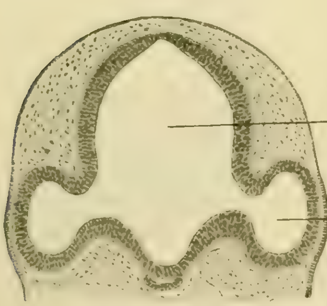
A collection of mucus or pus in the lachrymal passage is usually in the sac, and when not otherwise relieved, it tends to discharge itself through the skin below the tendo oculi, and frequently lower than the level of the sac. The abscess is therefore opened below the tendon and external to the inner edge of the lachrymal groove.

The *line* of the sac and duct, taken together, is approximately from the inner canthus to the space between the second premolar and first molar teeth. It opens below into the inferior meatus of the nose, just below and behind the anterior end of the inferior turbinate bone, which conceals it from view at the anterior naris. The sac and duct form a slightly curved line with its convexity backward, and its course downward, backward and slightly outward. To pass a probe along the lachrymal passage, the lower lid is everted by the thumb so that the punctum may be seen. The probe should be entered into the punctum vertically. It should then be turned horizontally and passed through the canaliculus to the inner wall of the lachrymal sac. It is then made vertical and passed along the duct—*i.e.*, downward, slightly backward, and outward to the nose.

DEVELOPMENT OF THE EYE.

The development of the eye begins as a lateral diverticulum which very early appears on either side of the fore-brain (Fig. 911). These outgrowths, the **primary optic vesicles**, are hollow and directly communicate with the general cavity of the primitive brain by means of the **optic stalks**, which are at first broad, but later become narrowed. As the development proceeds, the transversely placed optic stalks gradually assume a more oblique axis, and, after the differentiation of the fore-brain into its two subdivisions, open into the diencephalon or inter-brain. The primary optic vesicle expands until it comes into contact with the surface ectoblast. The next important step is a thickening of the wall of the vesicle where it is in contact with the ectoblast (Fig. 1238). In consequence of the rapid multiplication of its cells, this portion of the wall becomes invaginated and, as a result, the cavity of the primary optic vesicle is gradually obliterated, the application of the invaginated portion of the wall to the inner surface of the uninvaginated part of the vesicle bringing about the formation of a cup-shaped structure provided with a double wall. This cup is called the **secondary optic vesicle** and from it the retina is developed, which must be considered, therefore, as a modified portion of the brain itself.

FIG. 1237.



Part of frontal section of head of early rabbit embryo, showing optic vesicles evaginated from brain-vesicle. × 30.

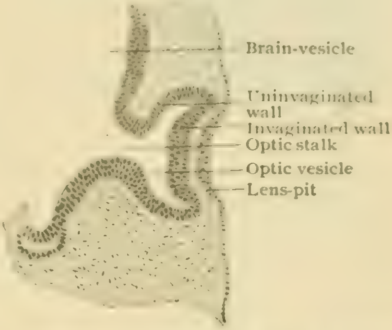
Coincidentally with the invagination of the optic vesicle, the overlying ectoblast undergoes active proliferation and pushes into the space vacated by the receding invaginated wall, thus producing a depression known as the **lens-pit**. The lens-pit (Fig. 1238) deepens and becomes cup-shaped; the edges of its anterior walls approach each other and then fuse, and in this manner form a closed sac, the **lens-vesicle**. This remains for a time connected with the surface ectoblast, but later becomes separated from it and forms an isolated sac of epidermal tissue, which, by the proliferation of its cells, becomes converted into a solid structure and constitutes the crystalline lens. At first the lens-vesicle fills the cavity of the optic cup completely, but with the deepening of the latter, a space appears between its anterior wall and the lens-vesicle, which gradually widens and forms the **vitreous cavity**. The space between the lens-vesicle and the ectoblast is invaded by a process from the surrounding mesoblast, which pushes in from the side. From this ingrowth is developed the cornea, with the exception of the surface epithelium, and the stroma of the iris.

Almost from the first appearance of the invagination of the primary optic vesicle, the invaginated portion of the wall exhibits a marked tendency to proliferation of its cells. The

uninvaginated portion of the wall, on the contrary, gradually becomes thinner, until it is represented by a single layer of cubical cells. These soon assume a dark color in consequence of the appearance within their protoplasm of fine pigment particles. From this wall, therefore, the layer of pigmented cells composing the outermost stratum of the retina is developed, whilst from the rapidly augmenting layers of the inner wall, the essential nervous elements of the retina, together with the supporting neurogliar tissue, are formed.

The invagination of the optic vesicle is not confined to its outer wall, but also affects its lower wall, in consequence of which a groove, the fœtal **ocular cleft**, appears in this position (Fig. 1240). This is continued backward to and along the under surface of the optic stalk, in the form of a furrow. By means of this slit a communication is established between the cavity of the secondary optic vesicle and the centre of the optic stalk, and through it blood-vessels from the surrounding mesoblast gain entrance to the interior of the nerve and the eyeball. The walls of this fœtal cleft gradually approximate and become fused. The imprisoned vessel, the hyaloid artery, later gives rise to the arteria centralis retinæ. The vitreous body has been usually considered as a derivative exclusively of mesoblastic tissue which entered the eye in company with the blood-vessels. According to the investigations of Schön, Kölliker, Wolfrum and others, however, this view is inadequate, since at least the anterior or ciliary portion of the vitreous is a product of the cells of the inner wall of the secondary optic vesicle. The choroid and the sclera are differentiated from the mesoblast, which surrounds the eyeball.

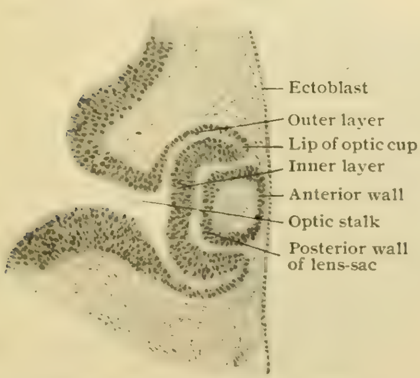
FIG. 1238.



Lens-pit shows as depressed area of thickened ectoblast; anterior wall of optic vesicle beginning to be invaginated; optic stalk narrowing. × 30.

Development of the Lens.—Soon after the isolation of the primitive lens-vesicle from the surface ectoblast, the cells in the posterior wall begin to proliferate actively, while those on the anterior wall are reduced to a single layer. The latter persists as the lining epithelium of the adult lens-capsule. By the growth of the cells of the posterior wall and their elongation into lens-fibres, the hollow vesicle is gradually converted into a solid mass of **lens-substance**, the fibres extending forward until they come in contact with the anterior wall. Subsequently the growth of the lens proceeds by the application of additional layers of fibres to the surface of the primary nucleus, the new fibres developing from the cells lining the anterior capsule. Their conversion takes place at the equator of the lens, where the nuclei of the elongating lens-fibre are arranged in a convex line known as the *nuclear zone* (Fig. 1228).

FIG. 1239.



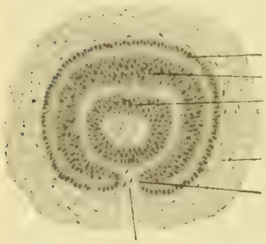
Lens-sac closed; outer and inner layers of secondary optic vesicle now almost in contact. × 30.

The **capsule** of the lens appears very early, even before the closure of the lens-vesicle, and long before the appearance of blood-vessels around the lens. It forms a sharp boundary line, at first along the posterior border, which gradually thickens and finally surrounds the entire lens. The capsule is to be considered as a secretion product of the lens-cells.

The rapid early growth of the young lens requires an adequate blood supply. This is insured by the development of a vascular net-work, the **tunica vasculosa lentis**, which completely surrounds the lens from the second month until the close of fœtal life, when this temporary membrane is absorbed. The chief supply of this vascular net-work is derived from the vessels of the vitreous, which, as already noted, enter the eye through the cleft in the optic nerve. Passing forward through the canal of Cloquet in the centre of the vitreous cavity, the chief vessel, the *hyaloid artery*, reaches the posterior pole of the lens, when it divides into numerous branches. These branches pass around the equator of the lens onto the anterior surface, where, joined by vessels from the mesoblastic tissue which is to constitute the future iris and ciliary body, they proceed to the centre of the pupil and break up into their terminal loops. The portion of the net-work covering the pupillary area is called the **membrana pupillaris**, whilst the remainder is known as the **membrana capsularis**. This vascular sheet is usually entirely absorbed before birth, but occasionally portions of it may be seen persisting in the form of fine threads in the pupillary space, or on the posterior pole of the lens. The retention of such strands is sometimes associated with the persistence of portions of the hyaloid artery.

Development of the Retina.—As already pointed out, the retina develops from the walls of the optic vesicle, the pigmented layer being derived from the uninvaginated outer wall, the pigment appearing early and first near the anterior margin of the optic cup; the remainder of the retina comes from the rapidly growing cells of the inner wall. The first cells to be differentiated in the nervous portion of the retina are the *spongioblasts* which develop into the supporting neurogliar fibres, the *fibres of Müller*. These are strengthened by the addition of mesoblastic elements, which enter the inner layers along with the blood-vessels. The *neuroblasts* develop from cells which correspond in position to those of the external nuclear layer. As they divide, the cells are displaced inward, so that the ganglion-cells represent the oldest descendents. When seven or eight layers have been differentiated, the ganglion-cells send out axones, which form the fibre-layer and converge toward the optic nerve. The visual cells are the last to appear, the layer of rods and cones developing as cuticular outgrowths from the cells of the external nuclear layer.

FIG. 1240.

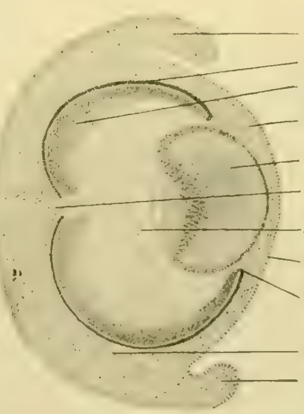


Sagittal section of developing eye at same stage as preceding specimen, showing invagination of optic vesicle along fœtal cleft. × 30.

Anteriorly the walls of the secondary optic vesicle are reduced to a double layer of cells. For a certain distance, corresponding to the position of the future ciliary body (pars ciliaris retinæ), the outer cells are pigmented, whilst the inner ones are transparent. Still farther forward, the rudimentary portion of the nervous tunic is continued over the posterior surface of the iris (pars iridica retinæ) as a double layer of deeply pigmented cells which extends as far as the pupillary margin which thus corresponds to the anterior lip of the secondary optic vesicle.

The **optic nerve** is developed secondarily and in close association with the early optic stalk, which is at first hollow, and later becomes grooved along its inferior surface. The walls of this *fœtal cleft* become approximated and, after the entrance of the blood-vessels, the lips of the cleft fuse, the vessels being thus enclosed. Since the fibres of the optic nerve are for the most part axones of the ganglion-cells of the retina, it is evident that they are not developed within the nerve, but invade the latter as outgrowths of fibres from the retina, pushing along the optic nerve and tract to reach their cerebral connections. In addition to these centripetal fibres, a certain number of centrifugal ones appear later as outgrowths from cells within the brain. The supporting tissue is developed by proliferation of the cells of the optic stalks and their differentiation into neurogliar elements, assisted by the mesoblastic elements from the surrounding pia and the portion which enters the cleft with the blood-vessels. The nerve-fibres are at first naked axis-cylinders, which later acquire medullary sheaths.

FIG. 1241.



Much later stage, showing lens now solid; layers of optic vesicle converted into retinal coat; vascular vitreous tissue; condensation and invasion of mesoblast. × 20.

Development of the Fibrous and Vascular Tunics.—With the separation of the lens-vesicle from the overlying ectoblast, the mesoblast insinuates itself between these structures, in addition to surrounding the entire ectoblastic optic vesicle. The portion surrounding the optic vesicle posteriorly thickens rapidly and becomes differentiated into the vascular tunic, or choroid, whilst the outer layer becomes the fibrous tunic, or sclera. The **choroid** appears first, the pigmentation of its cells being evident by the seventh month. The mesoblastic process between the lens and the ectoblast is very thin at first, but subsequently splits into two layers. The anterior of these becomes the substantia propria of the **cornea** and its lining endothelium. The latter produces the membrane of Descemet. The posterior mesoblastic layer carries blood-vessels which help to form the capillary net-work surrounding the lens. The space between the two mesoblastic layers represents the future anterior chamber of the eye. About the fourth fœtal month the anterior lip of the optic vesicle pushes forward in advance of the lens and carries with it additional mesoblastic tissue. From this the **iris** is developed, the stroma being formed by the mesoblast, whilst the posterior pigmented portion represents the anterior part of the optic vesicle, from which the dilatator muscle (and, according to some authorities, also the sphincter pupillæ) is derived. The **ciliary processes** are produced by the rapid lateral expansion of the walls of the

optic vesicle, about the fourth or fifth month, in consequence of which folds in the membrane arise, into which blood-vessels and other mesodermic elements extend. The corneal stroma becomes blended with the sclera, thenceforth the two forming a continuous tunic.

Development of the Vitreous Body.—As already stated, the vitreous body is at present regarded as developing, at least in part, from the cells of the inner wall of the optic vesicle, especially from its anterior or ciliary portion. The **suspensory ligament** of the lens is derived from the same source. The cells develop into the fibres which form the fine net-work of the vitreous body; at the periphery these become condensed and form the boundary layer or **hyaloid membrane.** The vitreous is supplied with blood by branches of the hyaloid artery, which springs from the head of the optic nerve. An especially complete net-work is found at the periphery of the vitreous and these vessels pass forward to the equator of the lens and assist in forming the tunica vasculosa lentis. The retinal vessels are formed later as branches of the central artery, the vitreous vessels usually undergoing complete absorption before birth.

The **development of the eyelids** begins with the production of folds of integument, which appear above and below the cornea during the second fœtal month. The folds approach each other and the epidermal cells fuse about the third month, the eyelids remaining united until shortly before birth. The Meibomian and other glands of the lids are produced by ingrowths of the surface ectoblast. The **lachrymal gland** arises during the third month as a solid ingrowth from the conjunctival epithelium close to the upper lid. The **lachrymal canal** begins as a solid process of epithelial cells from the lid, which dips inward along the lachrymal furrow, between the superior maxillary and nasal processes. This cord of cells becomes isolated from the surface, and later acquires a lumen, connecting by means of the canaliculi with the conjunctival sac above. The duct establishes communication with the nasal fossa just before birth.

THE EAR.

The ear (**organon auditus**) may be conveniently studied under its three natural subdivisions, which are conventionally described as the external, middle and the internal ear—structures lodged entirely or in part within the temporal bone. The

FIG. 1242.

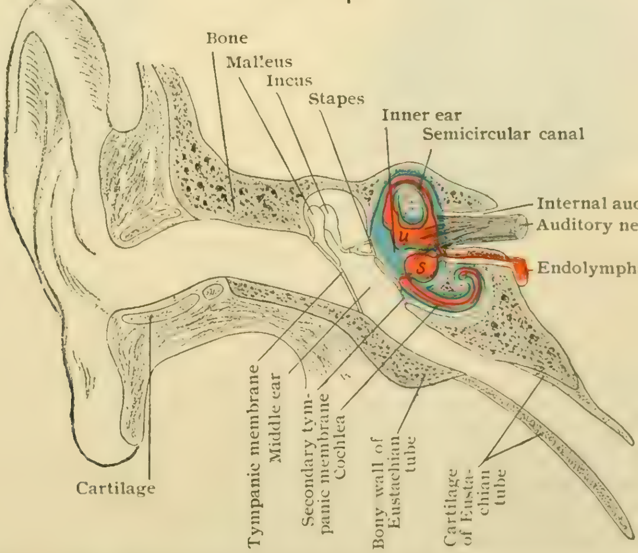


Diagram showing relations of three subdivisions of ear. (*Modified from Schwalbe.*)

external ear includes the auricle and the external auditory canal; the *middle ear* the tympanum, the Eustachian tube and the mastoid cells; and the *internal ear* the labyrinth, with the peripheral ramifications of the auditory nerve.

Such division, moreover, is justified by the developmental history of the organ, since the internal ear is developed essentially from the highly differentiated otic vesicle which gives rise to the complicated membranous labyrinth; the middle ear largely from the first pharyngeal pouch; whilst the external ear represents the deepened and modified boundaries of the first external visceral furrow.

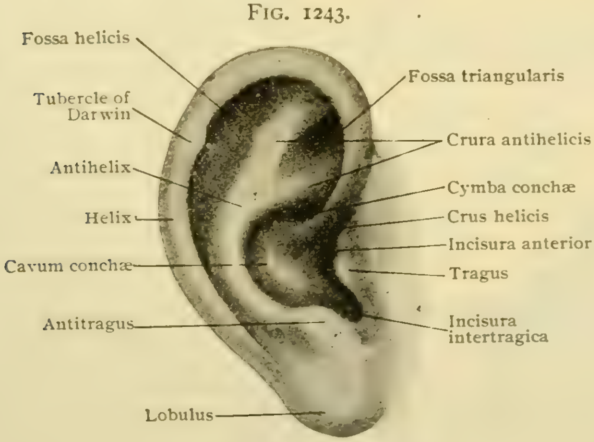
THE EXTERNAL EAR.

The external ear, the outermost subdivision of the auditory organ, includes (1) the *auricle*, the funnel-shaped appendage attached to the side of the head for the collection of the sound-waves, and (2) the *external auditory canal*, which conveys these stimuli to the tympanic membrane, the flexible partition closing the canal and separating it from the middle portion of the ear.

THE AURICLE.

The auricle (**auricula**), also called the *pinna*, is attached to the side of the head around the opening of the external auditory canal, midway between the forehead and the occiput. It presents two surfaces, an external and an internal. The angle which its internal surface forms with the head, the *cephalo-auricular angle*, is usually about 30°, but varies from 20–45°. The circumference of the auricle is somewhat pyriform in outline, with the broadest part of the figure above. The external surface of the auricle is irregularly concave and presents for examination several well-marked depressions and elevations, which depend, for the most part, upon the corresponding modelling of the underlying cartilage. The **concha,** the largest and deepest of the concavities, surrounds the entrance or meatus to the external auditory canal. This funnel-like fossa is subdivided by an obliquely transverse ridge, the **crus helicis,** continuous with the helix, into the upper and smaller part, the **cymba conchæ,** and a lower and larger part, the **concha proper** or **cavum conchæ.** The **tragus** is an irregular eminence in front of, and slightly overlapping, the meatus. At the upper extremity of the tragus, just below a notch, the **incisura anterior,** that separates the tragus from the upper part of the auricle, is sometimes seen a small elevation, the **tuberculum supratragicum.** The **antitragus** is an eminence behind the tragus and separated from it by a deep notch, the **incisura intertragica.** The **lobule** contributes the rounded lower extremity of the auricle. In contrast to other parts of the pinna, it possesses no framework of cartilage and, hence, is soft and inelastic. The **helix** forms the scroll-like margin of the ear, sweeping from the upper part of the tragus in front to the lobule behind. It is more or less rolled upon itself so that its margin looks forward. On the anterior edge of the helix, near the junction of its upper and middle thirds, is sometimes found a small triangular elevation, the *ear-point* or *tubercle of Darwin*, which is of interest as representing, according to the last-named authority, the erect pointed extremity in the expanded ears of certain quadrupeds. It is said to be constant in the fœtus of about the sixth month and to be more common in the male than in the female. In front of and parallel to the helix, is a curved ridge, the **antihelix** which begins at the antitragus below, forms the concave posterior boundary of the concha, and divides above it into a superior and an inferior crus between which lies the **fossa of the antihelix** or the **fossa triangularis.** A narrow groove between the helix and the antihelix marks the **fossa of the helix** or the **scaphoid fossa.**

FIG. 1243.



Right auricle, outer aspect.

The elevations on the **external surface** of the auricle are represented by depressions on the cranial surface, and conversely the depressions on the external

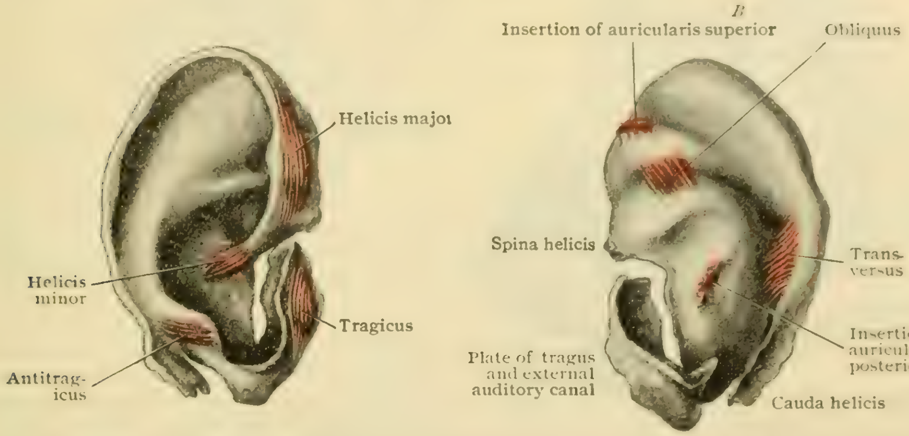
surface are represented by eminences. Thus, the concavity of the concha is represented on the cranial surface by the **eminentia conchæ**; the antihelix by the **fossa antihelicis**; the fossa triangularis by the **eminentia fossæ triangularis**; the scaphoid fossa, by the **eminentia scaphæ**. The other elevations and depressions corresponding to those of the outer surface are not seen on the cranial surface, except in the dissected cartilage denuded of the integument.

Structure of the Auricle.—The auricle consists of integument and an enclosed plate of yellow elastic cartilage continuous with that of the meatus. It is also provided with several unimportant ligaments and muscles. The lobule, however, contains no cartilage, but only fibrous tissue and fat enclosed within the integumentary fold.

The skin of the auricle is thin and closely adherent to the cartilage, especially on the outer surface. In certain parts it contains fine hairs and sebaceous and sweat glands. The hair follicles are especially abundant over the tragus, antitragus and the notch lying between them, the hairs guarding the entrance into the external auditory canal, known as **tragi**, being exceptionally long. The sebaceous glands are especially well developed in the cavity of the concha.

Cartilage of the Auricle.—The cartilage of the auricle may be divided into two parts: (*a*) the scroll-like plate forming the tragus and external auditory canal, and (*b*) the large irregular plate forming the main cartilage. These two divisions

FIG. 1244.



Cartilaginous framework of right auricle, with intrinsic auricular muscles; *A*, outer, *B*, inner surface.

are connected by a cartilaginous isthmus lying between the incisura intertragica on its outer side and the deep fissure, (**incisura terminalis auris**), which in the isolated cartilage is seen between the posterior wall of the outer meatus and the anterior border of the lower part of the concha, on its inner side. Two smaller clefts, the **fissures of Santorini**, are found between the three plates which form the cartilaginous scroll supporting the tragus and outer end of the external auditory canal. The cartilage of the tragus is an irregular plate and subject to considerable variation.

The depressions and elevations of the cartilage proper correspond in general to the surface modelling of the auricle, but are sharply marked, especially on the cranial aspect. A deep notch, the **fissura antitragohelicina**, separates the lower part of the helix from the antitragus, thus defining the **caudal process** (**cauda helicis**), as the lower extremity of the cartilage forming the helix is called.

The **spina helicis** is a small conical projection, directed forward and downward, opposite the first bend of the helix. This serves for the attachment of the anterior ligament. The upper end of the tragus-plate fits into an angle formed by the junction of the beginning of the helix and the upper end of the anterior border of the concha. In addition to the elevations and depressions already referred to, on the mesial surface is found a ridge, the **ponticulus**, which extends downward and forward over the eminence of the concha and serves for the attachment of the posterior auricular muscle (Fig. 1244, *B*).

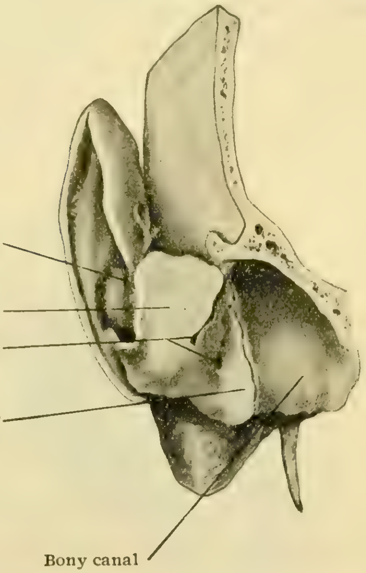
Ligaments of the Auricle.—The **extrinsic ligaments** of the auricle, those which attach the auricle to the temporal bone, form a more or less continuous mass of fibres. These are separated somewhat arbitrarily and described as the anterior and posterior ligaments. The **anterior ligament** extends from the helix and the tragus to the root of the zygoma. The **posterior ligament** extends from the eminence of the concha and ponticulus to the anterior part of the mastoid process. A number of bands of fibrous tissue, the **instrinsic ligaments,** bind the parts of the cartilage together.

The Muscles of the Auricle.—These include the extrinsic and the intrinsic muscles.

The **extrinsic muscles** of the auricle, those which extend from the head to the auricle and move it as a whole, have been described under the muscular system (page 483). They are the anterior, superior and posterior auricular muscles.

The **intrinsic muscles,** six in number, consist of small strands of muscle-fibres attached to the skin, which extend from one part of the auricle to another and are confined to the auricle itself. Of these, four are on the external surface of the auricle and two on the cranial.

FIG. 1245.



Dissection showing bony and cartilaginous portions of right external auditory canal; seen from in front.

1. The **smaller muscle of the helix** (*m. helicis minor*) lies upon the crus helicis and the beginning of the helix, its fibres running obliquely upward and forward.

2. The **greater muscle of the helix** (*m. helicis major*) arises from the spine of the helix and extends upward along the anterior border of the helix and is inserted into the eminence of the triangular fossa.

3. The **muscle of the tragus** (*m. tragicus*) is a flat muscle on the outer surface of the tragus; usually only its vertical fibres are distinguishable. Occasionally a separate bundle of muscular fibres (*m. pyramidalis*) extends from the tragus to the spine of the helix. Likewise another band, the *m. incisuræ Santorini*, sometimes called the *dilatator conchæ*, bridges the greater incisura Santorini. Both of these, however, belong to the system of the tragus muscle.

4. The **muscle of the antitragus** (*m. antitragicus*) is attached to the outer surface of the antitragus. Its fibres run obliquely from the antitragus upward and backward and are inserted into the caudate process of the helix. On the cranial surface of the auricle are the transverse and the oblique muscles.

5. The **transverse muscle** (*m. transversus*) bridges over the fossa antihelicis and extends from the eminence of the scaphoid fossa to the eminence of the concha.

6. The **oblique muscle** (*m. obliquus*), considered by Gegenbauer as a part of the transverse muscle, extends from the back of the concha to the eminence of the triangular fossa.

Actions.—Duchenne and Ziemssen found that by stimulating the muscles of the tragus and antitragus the external auditory canal was narrowed. Duchenne further demonstrated that the greater and lesser muscles of the helix were antagonistic to those of the tragus. The transverse muscle and the oblique muscle by their contraction are said to cause a slight flattening of the auricle.

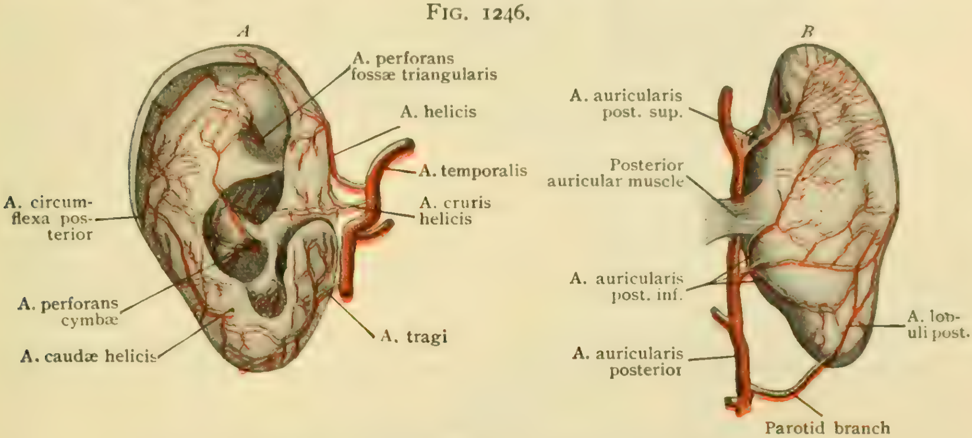
Vessels of the Auricle.—*Arteries.*—The auricle receives its blood supply from branches of the superficial temporal artery and the posterior auricular artery, and thus indirectly from the external carotid. The superficial temporal sends three branches to the outer surface of the auricle: (*a*) the *artery of the helix* to the ascending part of the helix, fossa triangularis and the superior crus of the antihelix; (*b*) the *artery of the crus helicis* to the region of the crus helicis; (*c*) the *artery of the tragus* to the region of the tragus and lobule, the lobule receiving

a branch, the *anterior artery of the lobule*, from the artery of the tragus. The posterior auricular artery supplies a variable number of branches to the auricle. Usually two of these are given off below and one above the posterior auricular muscle. These branches are larger and longer than those from the superficial temporal. After ramifying over the cranial surface of the auricle, they reach its outer surface by piercing the auricle or by passing over its free margin. They supply the posterior part of the outer surface and anastomose with the branches of the superficial temporal.

The *veins* of the auricle accompany the arteries and include: (*a*) the anterior auricular, which empties into the superficial temporal; (*b*) the posterior auricular, three or four in number, which join a plexus behind the ear which empties principally into the external jugular vein, but also unites with the posterior facial vein. Communications with the mastoid emissary vein of the lateral sinus also frequently exist.

The Lymphatics.—The lymphatics of the auricle form a close net-work within the deeper layers of the integument, from which lymphatic stems pass in three general groups. Those from the outer surface are afferents chiefly of the anterior auricular nodes, which are placed immediately in front of the tragus and beneath the parotid fascia; a few, however, bend backward over the helix to end in the posterior auricular nodes that overlie the insertion of the sterno-mastoid muscle. Those from the upper part of the cranial surface pass mainly to the posterior auricular nodes, some being tributary to the external jugular nodes. A number of stems from the lower part of the auricle and from the lobule terminate in the parotid nodes.

FIG. 1246.



Arteries of right auricle, *A*, lateral surface; *B*, postero-mesial surface. (*Schwalbe.*)

Nerves of the Auricle.—The *motor nerves* supplying the intrinsic muscles of the auricle are from the temporal and posterior auricular branches of the facial nerve, the former being distributed to the muscles of the helix, tragus and antitragus, whilst the posterior auricular supplies the tranverse and oblique muscles. The *sensory nerves* include branches from: (*a*) the great auricular nerve, which supplies the integument of the lower three-quarters of the inner surface of the auricle, with the exception of a small portion near the meatus, and sends filaments to the outer surface of the lobule and adjacent area; (*b*) the small occipital nerve, which supplies the upper one-quarter of the inner surface; (*c*) the auricular branch of the vagus, which supplies the small muscles on the back of the concha and a limited cutaneous area near the meatus; and (*d*) the auriculo-temporal nerve, which divides at the level of the tragus, and sends filaments from its auricular branches to the outer surface of the auricle.

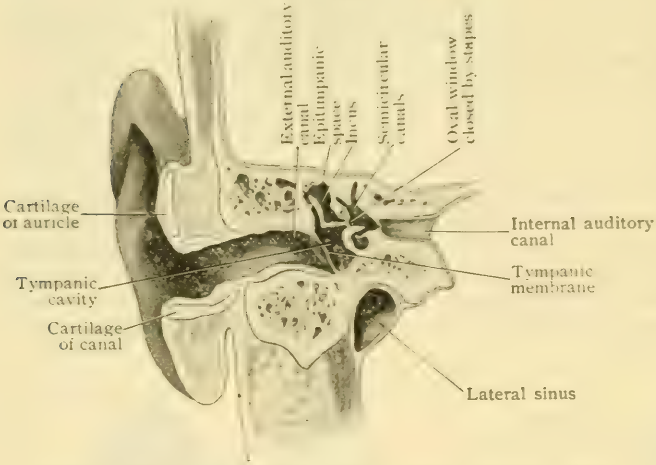
The External Auditory Canal.

The external auditory canal (**meatus acusticus**) leads from the cavity of the concha to the tympanic membrane, which closes its inner extremity. Although the adult meatus varies considerably in size and direction, it is usually tortuous.

In a general way, in its external portion the canal extends somewhat forward and inward, perhaps slightly upward; then, in its middle portion, almost directly

inward, possibly slightly backward; and finally, in its internal portion, forward, downward and inward. Its supero-posterior wall measures about 25 mm. (1 in.) in length, and the anterior wall about 35 mm. (1⅜ in.), the greater length of the anterior wall being due to the obliquity of the drum-head and the outward protrusion of the tragus. The canal is almost as long in the infant as in the adult.

FIG. 1247.

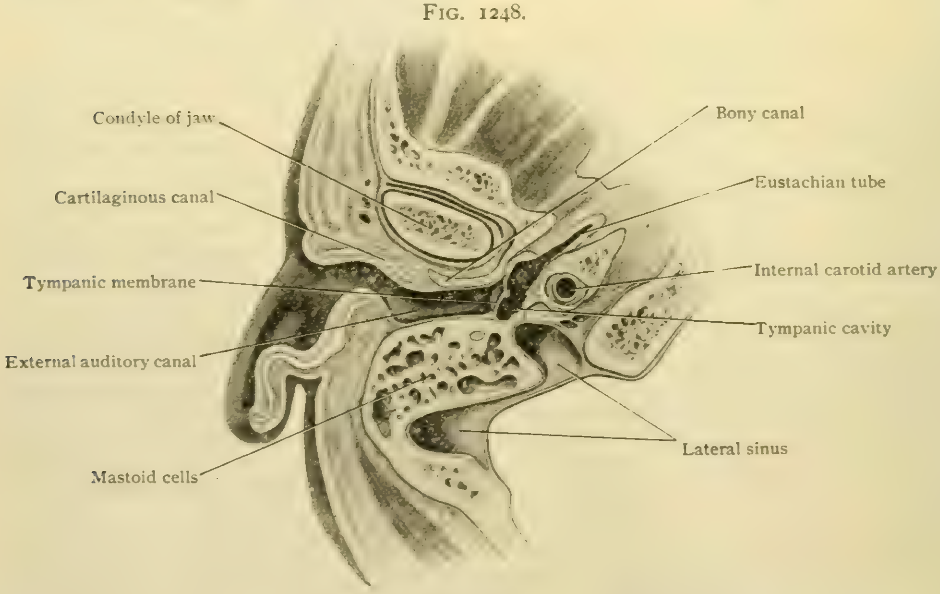


Frontal section passing through right ear, showing external, middle, and internal divisions; section is seen from in front.

Structure.—The external auditory canal is composed of an outer cartilagino-membranous (cartilaginous) and of an inner bony portion, both of which, as well as the external surface of the tympanic membrane, are lined by skin. The **cartilagino-membranous part** contributes something more than one-third of the entire length of the canal, and is a continuation of the cartilage of the auricle. The cartilage of the canal, histologically of the elastic type, does not form a complete tube, but is deficient at its upper back part, where it is filled in by fibrous tissue. On approaching the bony portion, this deficiency in the cartilage is more marked and the fibrous tissue correspondingly increased.

Two or more slit-like apertures, the **fissures of Santorini** (**incisurae cartilaginis meatus acustici externi**) are usually found traversing the cartilagino-membranous canal nearly at right angles (Fig. 1245); as they are filled with fibrous tissue, they permit the anastomosis between the vessels of the anterior and posterior surfaces

FIG. 1248.



Horizontal section passing through right ear, viewed from below.

of the ear. At its inner end the cartilagino-membranous meatus is attached to the inferior and lateral edges of the osseous meatus, the fibrous part being continuous superiorly and posteriorly with the periosteal lining of the osseous canal. The **osseous portion** of the tube, about 14 mm. in length, is longer and narrower than the cartilagino-membranous part. At its inner end it presents a narrow groove, the **sulcus tympanicus**, for the insertion of the tympanic membrane. The sulcus extends around the sides and floor of the canal, but is deficient above.

The **skin** lining the external auditory canal is closely attached to the underlying cartilaginous portion of the tube. The skin measures about 1.5 mm. in thickness, but is much thinner within the bony canal, except along the roof, where it remains relatively thick. Over the outer surface of the tympanic membrane the skin is reduced to a very delicate and smooth investment, covered by a correspondingly attenuated epidermis, and a suggestion of subcutaneous tissue. Numerous fine hairs and large **sebaceous glands** occur in the cartilaginous portion, but diminish in size and frequency towards the bony canal, in which they are entirely wanting. Within the cartilaginous meatus and along the roof of the bony tube, the skin is closely beset with the large coiled **ceruminous glands,** which resemble in structure modified sweat glands. Like the latter, the ceruminous glands consist of a deeper and wider coiled portion, the *secretory segment*, and a long narrow *excretory duct*, which ends in most cases independently on the free surface of the skin, but sometimes, particularly in the very young child, it opens into the duct of a sebaceous gland. The cuboidal secreting cells contain yellowish brown pigment particles and granules resembling fat. The **ear-wax** or **cerumen** is, as usually found, the more or less dried mixture of the secretions derived from both varieties of glands, together with discarded squamous epidermal cells.

FIG. 1249.

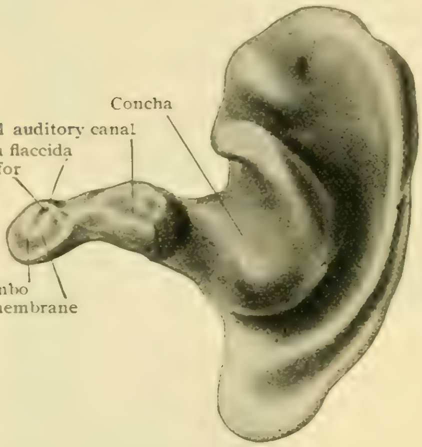
Transverse section of skin lining cartilaginous portion of external auditory canal. × 30.

Vessels.—The *arteries* distributed to the external auditory canal are from three sources: (*a*) anterior branches of the superficial temporal supply the external portion of the meatus; (*b*) the deep auricular artery, a branch of the internal maxillary, passes to the deeper portions; whilst (*c*) the posterior auricular provides branches for the posterior and superior surfaces. The arteries destined for the interior of the canal pierce the membranous roof of the cartilaginous meatus, the fissures of Santorini and the fibrous tissue connecting the cartilaginous with the bony portion of the tube. They form capillary net-works within the perichondrium and periosteum and,

within the skin, around the glands and the hair follicles, some extending on to the upper part of the membrana tympani. The deeper *veins* of the meatus, which drain the bony and a small part of the cartilaginous meatus, empty into the venous plexus behind the articulation of the lower jaw, those from the upper wall of the meatus extending upward to join the venous plexus which spreads out over the skull.

The *lymphatics* of the external auditory canal arise from a cutaneous net-work from which trunks pass in three general groups, as do those of the auricle. (1) The trunks of the *posterior* group arise in the posterior wall of the external meatus and empty, for the most part, into the posterior auricular (mastoid) nodes. Some, however, avoid this first station and join the efferent vessels of the upper nodes of the superior deep cervical chain. (2) The *inferior group* includes a variable number of trunks coming from the lower wall of the external auditory meatus, some of which pass to the nodes placed along the course of the external jugular vein at its exit from the parotid, whilst others end in the mastoid nodes. (3) The *anterior group* is from the concha and the anterior wall of the meatus. These vessels are tributary to the parotid nodes, more particularly to the anterior auricular nodes situated immediately in front of the tragus.

FIG. 1250.



Cast of right external auditory canal, seen from behind; natural size. Drawn from cast made by Professor Randall.

Nerves.—The sensory nerves supplied to the external auditory canal are derived from the auriculo-temporal branch of the trigeminus and from the auricular branch of the pneumogastric. The latter, also known as Arnold's nerve, perforates the wall of the meatus and supplies its lining membrane.

Practical Considerations: The Auricle.—The auditory mechanism may be said to consist of two portions—that which conducts the sound and that which receives it. The former is represented by the external and the middle ear; the latter, by the internal ear. The function of the auricle is to collect and intensify the sound-waves and to direct them into the external auditory canal. That it does not play a very important part in hearing is shown by the fact that its removal has been followed by comparatively little loss in the acuteness of hearing (Treves). Complete absence of the auricle is exceedingly rare; partial defect (*microtia*) is more frequent; while congenital fistulæ are comparatively common. These *fistulæ* are considered to be due to a defective closure of the first branchial cleft. According to His, however, they are due to deficient union of the crus helicis and the crus supratragicus. If a fistula closes at its orifices, a retention cyst, sometimes dermoid, may result. The ear may be abnormally large (*macrotia*), or, as a result of defective union of the rudimentary tubercles from which the auricle is developed, auricular appendages (*polyotia*) may be met with. A supernumerary auricle may very rarely be found on the side of the neck at the orifice of one of the lower branchial clefts.

Owing to the rich blood-supply of the auricle, wounds heal rapidly. When, however, they occur near the external auditory meatus and are large, cicatricial closure of the canal must be guarded against.

Frost-bite is frequent because of the exposure to cold and the lack of protection to the blood-vessels from overlying tissues, since little more than skin covers them. An intense reactive congestion follows, and frequently leads to gangrene.

The skin is closely adherent to the underlying tissues, especially on the anterior surface, so that the exudate is under much tension, interfering with the blood-supply. The nerves are also compressed, accounting for the great pain.

Hæmatomata of the auricle are due to effusions of blood between the cartilage and its perichondrium. They occur usually on the concavity of the auricle from a blow, as in boxers, or foot-ball players. They may occur rarely, without traumatism, as in the insane, although some believe that injury is the exciting cause in these cases; or even, in very exceptional instances, may appear without precedent trauma or mental disease. In those cases in which there is great tension, it may be necessary to incise and drain to prevent necrosis.

Of the *tumors*, keloid, following punctures for ear-rings, is common in the negro; capillary nævi are frequent, whilst cirsoid aneurism may occur. Cysts in connection with the first branchial cleft have already been mentioned.

The External Auditory Canal.—*Congenital atresia* is rare and is often associated with malformations of the auricle, the middle and the internal ear, so that correction of the external condition will usually fail to restore the hearing.

The length of the external meatus is about 1¼ inches, about ¾ inch of which is bony and about ½ inch cartilaginous. In the new-born it consists of skin and cartilage only, and its lumen is very small. Owing to the obliquity of the tympanic membrane, that structure, in the new-born, is in close contact with the floor of the canal, so that the latter must be drawn away from the membrane to expose it. For this purpose the auricle should be drawn downward and backward. The skin of the cartilaginous portion is supplied with hair, sebaceous and ceruminous glands. Furuncles are frequent, the infection passing along the hair-follicles to the associated sebaceous glands. In some persons, one boil follows another from successive glandular infection. The skin of the bony portion is thinner than that of the cartilaginous, except in the posterior part of the roof, where a thicker wedge-shaped piece containing glands extends as far as the drum-head.

Ceruminous masses often collect, and frequently contain pathogenic bacteria. They may press upon the tympanic membrane, and through intralabyrinthine pressure may produce vertigo, or may lead to vomiting or convulsions. Interference by the mass with air conduction may result in loss of hearing.

A diffuse infection of the meatus may be primary, but it is more apt to be a secondary result of otitis media. In severe cases the pus may extend to the bone separating the periosteum. It may then pass to the parotid region through the anterior bony wall, but it is more likely to do so through the fissures in the cartilaginous portion. Abscesses in the parotid region more frequently extend by the same route in the reverse direction.

The general *direction* of the canal is from without inward, downward, and slightly forward. The auricle and cartilaginous meatus are suspended from the margin of the bony portion so that an angle is formed opening downward. For a short distance from the external orifice the meatus inclines forward. In the remaining cartilaginous portion it turns backward, while in the bony portion it is again deflected forward. Therefore, to examine the tympanic membrane the cartilaginous meatus must be drawn upward to correct the vertical curve, and backward to straighten the antero-posterior curve.

The diameter of the canal is greater at the two extremities than in the centre. The smallest diameter in the bony portion is at the inner third, where foreign bodies most frequently lodge, which have been known to remain in the canal for years without much discomfiture, or even, in some cases, without their presence being known. Care is necessary in their removal lest the tympanic membrane be injured.

The *anterior wall* of the meatus is in relation with the temporo-maxillary articulation, and its bony portion has been fractured from blows upon the lower jaw. The parotid gland is in relation with this wall as well as with the floor, so that tumors of the gland may narrow or occlude the canal by pressure. Parotid abscesses opening into the canal are likely to pass through the deficiencies in the cartilage (fissures of Santorini). Since the lower jaw is in relation with the cartilaginous as well as with the bony portion of the meatus, the former is drawn forward when the mouth is opened. Hence the mouth is usually opened when one listens intently.

The *posterior wall* is separated from the mastoid process by the tympano-mastoid fissure. The auricular branch of the pneumogastric (Arnold's nerve) passes through this fissure to the posterior wall of the canal. The coughing, sneezing, or vomiting that sometimes follows irritation of the canal, as from cleaning the ear, or examining it with instruments, is said to be due to a reflex effect upon the pneumogastric through this branch. The auriculo-temporal branch of the trigeminal nerve enters into its supply, and may explain the earache in cancer of the tongue or disease of the lower teeth. Between the posterior wall of the meatus and the mastoid cells is a thin plate of bone one or two millimeters in thickness. The sigmoid portion of the lateral sinus is usually about 12 mm. back of this wall, and the mastoid antrum about 5 mm. posterior to its deeper portion.

The *superior wall*, which is from 4–5 mm. in thickness, often contains air-cells between two plates of compact bone. Pus may burrow through it from the canal to the interior of the cranium. At the posterior superior angle of the canal are a number of small openings for blood-vessels and some connective tissue fibres, through or along which pus may find its way from the mastoid antrum to the under surface of the periosteum in the meatus.

THE MIDDLE EAR.

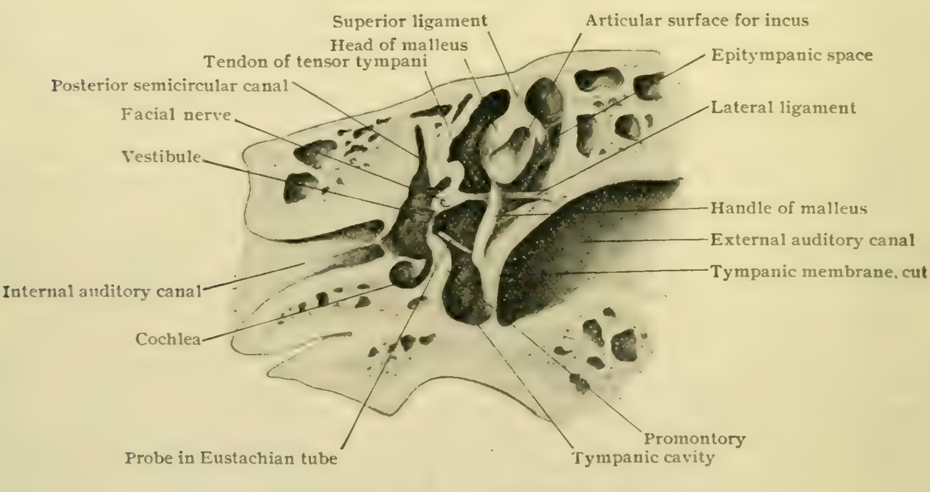
The middle ear includes three subdivisions : the *tympanic cavity*, the *Eustachian tube*, and the *mastoid cells*.

It is an irregular air-chamber, beginning on the lateral wall of the naso-pharynx with the Eustachian tube, which leads upward, backward and outward, for about one inch and a half into the temporal bone. Opposite the external auditory canal, it widens into the tympanic cavity and continues backward into the mastoid cells.

The Tympanic Cavity.

The tympanic cavity (**cavum tympani**), also called the **tympanum**, is an irregular space within the temporal bone, lying between the internal ear and the external

Fig. 1251.



Frontal section through right ear, viewed from behind. × 2½.

auditory canal. It is lined with mucous membrane and contains, in addition to the air which enters by way of the Eustachian tube, the chain of ear ossicles. Its shortest diameter, that between the middle of the tympanic membrane and the wall of the labyrinth, is about 2 mm. The antero-posterior diameter is about 12 mm., whilst the distance from the roof (tegmen tympani) to the floor, the supero-inferior diameter, is about 15 mm.

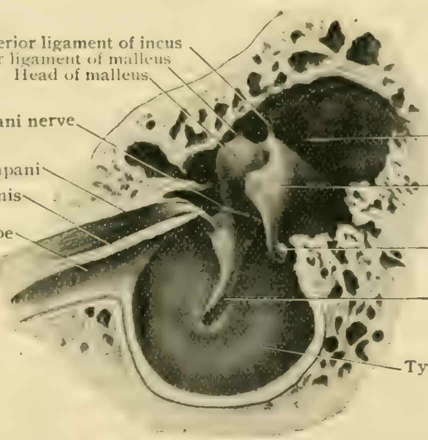
The cavity of the tympanum is subdivided into three parts: (1) the *atrium* or tympanic cavity proper; (2) the *cavum epitympanicum*, the upper part of the space which overlies the atrium; and (3) the *antrum*, which leads into the mastoid cells.

The **atrium** (Fig. 1251) resembles in shape a short cylinder with concave ends, the outer end being formed by the tympanic membrane and its bony margin, whilst the inner end is formed by the outer wall of the labyrinth.

The **cavum epitympanicum** or *attic* occupies the space between the atrium and the roof and constitutes approximately one-third (about 5 mm.) of the supero-inferior diameter. It contains the head of the malleus and the body of the incus (Fig. 1252). It extends considerably over the external auditory canal and is bounded laterally by a wedge-shaped portion of the temporal bone, called the scutum.

The **antrum tympanicum** is an irregularly pyramidal space communicating with the upper back part of the tympanum by a triangular orifice. Its dimensions vary, but its average length is about 12 mm., its height 8.5 mm., and its width 6.7 mm. It is larger in the infant than in the adult, and its lumen is frequently lessened by bands of mucous membrane which stretch across it and thus encroach upon the space. Its roof is formed by the tegmen tympani, sometimes called the *tegmen antri* in this location. Its external wall is formed by the squamous portion of the

FIG. 1252.



Inner aspect of outer wall of right tympanic cavity, showing incus and malleus and tympanic membrane in position. × 2½.

temporal bone, and on its internal one is seen the outer wall of the horizontal semicircular canal. The thin mucous membrane of the antrum is closely united with the periosteum and possesses a layer of low nonciliated squamous epithelium.

The **walls of the tympanic cavity** present many irregularities and depressions and the boundaries are not sharply defined. As the direction of the supero-inferior axis of the cavity is not perpendicular but oblique, it follows that the outer wall, composed of the tympanic membrane and its bony margin, is, accurately speaking, the infero-lateral wall, whilst that formed by the labyrinth is the dorso-mesial wall. For convenience of description, however, there may be recognized with advantage an *external* and an *internal*, a *superior* and an *inferior*, and an *anterior* and a *posterior wall.*

The **outer wall** (**paries membranacea**) of the tympanic cavity proper (the atrium) is formed by the drum-head and the margin of bone into which it is inserted, whilst the outer wall of the epitympanic space is formed by the scutum. In the infant the bony external auditory canal consists of a ring of bone, the **annulus tympanicus.** This ring, incomplete at its upper anterior part at the **notch of Rivinus,** possesses a well-marked groove, the **sulcus tympanicus,** for the reception of the tympanic membrane. At the notch of Rivinus, the tympanic membrane is attached to the bony margo tympanicus and the external lateral ligament of the malleus, and is continuous with the skin lining the bony auditory canal.

The Membrana Tympani.—The tympanic membrane or drum-head is a delicate transparent disc, irregularly oval or ellipsoidal in outline and concave on its outer surface. It is placed obliquely with the horizontal plane, forming an angle of about 55°, opening outward. As the middle portion of the membrane is drawn inward, the inclination of its several parts differs. The obliquity of the membrane is about the same in the infant as in the adult. With the upper back wall of the external auditory canal the drum-head forms a very obtuse angle, whilst with the antero-inferior wall it encloses an angle of about 27°. The longest diameter of the membrane is directed from above and behind, forward and downward, and measures from 9.5–10 mm.; the shortest is from 8.5–9 mm. The membrane is about .10 mm. thick, except at the periphery, where it is thickened. Like the rest of the tympanum and the labyrinth, it is practically as large in the infant as in the adult.

The handle of the malleus is embedded in the tympanic membrane (Fig. 1252), and extends from a point near the middle, upward and forward toward the periphery, to end at the short process. At its lower end, the handle of the malleus is flattened laterally and broadened at the **umbo**, which corresponds to the deepest part of the concavity of the membrane. The short process of the malleus forms a conspicuous rounded projection at the antero-superior part of the drum-head. Extending from the short process of the malleus to the anterior and posterior ends of the tympanic ring are two straight striæ. The part of the drum-head included between these striæ and the Rivinian notch is known as the **membrana flaccida** (pars flaccida) or **Shrapnell's membrane.** It is thinner and less tense than the remaining larger part of the drum-head which is called the **membrana tensa** (pars tensa).

The inner aspect of the drum-head presents two folds of mucous membrane which stretch horizontally backward and forward to the annulus and form an *anterior* and a *posterior* inverted *pocket*. The anterior pocket contains in its wall, in addition to the mucous membrane, the long process of the malleus, the chorda tympani nerve and the inferior tympanic artery, the nerve continuing along the lower border of the posterior fold.

The **structure** of the tympanic membrane includes three main layers: (1) the *middle fibrous stratum*, or *membrana propria;* (2) the *external cutaneous layer*, the prolongation of the skin lining the external auditory canal; and (3) the *internal mucous membrane*, a continuation of the mucous membrane clothing other parts of the tympanic cavity.

The **fibrous layer** or *membrana propria* represents the mesoblastic portion of the drum-head and consists of an outer stratum of radially disposed fibres which diverge from the malleus towards the periphery of the membrane, and an inner stratum of circular fibres, concentrically arranged and best developed near the periphery of the membrane but absent at the umbo. The radiating fibres, on the contrary, become more dense at the umbo, partly through accumulation and partly through splitting (Gerlach). Between the fibres of the two layers are seen connective tissue corpuscles which are spindle-shaped in longitudinal and stellate in cross-section.

The membrana propria is absent within the pars flaccida or Shrapnell's membrane. At the periphery of the membrana propria, the fibres, especially those of the radial stratum, are connected with those of a ring of thick connective tissue, the annulus fibrosus which occupies the sulcus tympanicus. The fibres of the annulus fibrosus run in various directions, but for the most part converge toward the tympanic membrane proper (Fig. 1253). Round cells are found between these fibres.

The **cutaneous layer** consists of a thin epidermal stratum, composed of two or three rows of cells and a delicate sheet of connective tissue, but neither a definite corium nor papillæ are present. A thickened band of subepithelial connective tissue extends across Shrapnell's membrane and along the handle of the malleus and contains the large vessels and nerves which pass from the meatus to the membrana tympani.

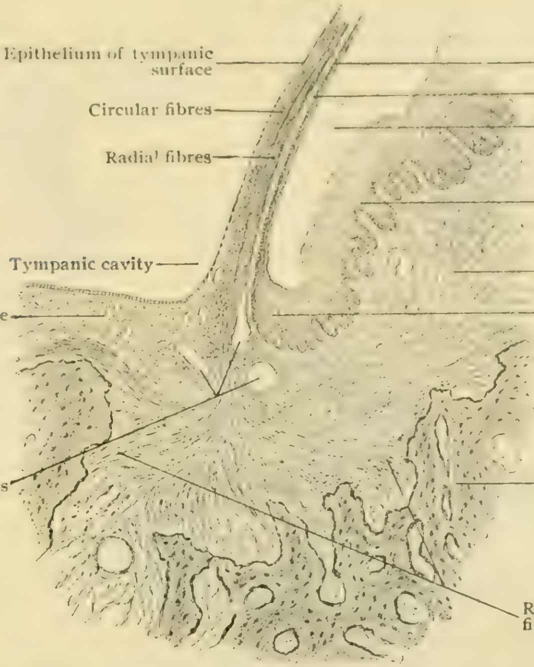
The **mucous membrane** covering the inner surface of the drum-head consists of a scanty layer of connective tissue, invested with a sheet of large low nonciliated epithelial cells.

The **vessels** of the tympanic membrane include *arteries* which are arranged as an outer and inner set, separated by the membrana propria. The former set is derived from the deep auricular branch of the internal maxillary artery; the latter from the tympanic branch of the internal maxillary and from the stylo-mastoid branch of the posterior auricular. Each of these sets forms a plexus of vessels with a large branch extending downward along the malleus handle, and another around the periphery of the membrane, these two branches being connected by numerous radiating twigs. Perforating vessels connect the two sets of arteries, especially along

the malleus handle and at the periphery of the membrane. The *veins* are most numerous at the handle of the malleus and periphery of the membrane and communicate with those of the external meatus and tympanic cavity.

The *lymphatics* are arranged similarly to the blood-vessels in two sets, one under the skin and the other under the mucous membrane. They communicate freely with each other and probably empty partly into the lymph-nodes situated over the mastoid process and in the region of the tragus, and partly into the lymph-tracts of the Eustachian tube and thence eventually into the retropharyngeal and deep cervical nodes.

FIG. 1253.



Section through attached margin of tympanic membrane, showing continuation of skin and mucous membrane over its outer and inner surfaces respectively. × 75. Drawn from preparation made by Dr. Ralph Butler.

The **nerves** supplying the tympanic membrane are derived chiefly from the auriculo-temporal branch of the trigeminus, supplemented by twigs from the tympanic plexus and by the auricular branch of the vagus. They accompany, for the most part, the blood-vessels and, in addition to supplying the latter, form both a subcutaneous and a submucous plexus.

The **inner wall** (**paries labyrinthica**) of the tympanic cavity separates it from the internal ear. It presents for examination a number of conspicuous features.

The **promontory** appears as a well-marked bulging of the inner wall near its middle (Fig. 1254) and corresponds to the first turn of the cochlea. The branches of the tympanic plexus are found in the mucous membrane covering it. At the bottom of a niche, whose anterior border is formed by the lower posterior margin of the promontory, lies the **round window** (**fenestra cochlea**). It is closed by the **secondary tympanic membrane** (**membrana tympani secundaria**), which separates the tympanic cavity from the scala tympani of the cochlea (Fig. 1259). The membrane is attached in an obliquely placed groove, is slightly concave toward the tympanum, and measures from 1.5–3 mm. in diameter. The **oval window** (**fenestra vestibuli**) lies at the bottom of a depression, the **fossula vestibuli,** in the upper back part of the inner wall, above the round window, and leads into the vestibule. It is somewhat kidney-shaped, its upper border being concave, its lower slightly convex. In the recent state the oval window is closed by the foot-plate of the stapes and the ligament which connects the ossicle with the sides of the window (Fig. 1260). The longest diameter of the latter is about 3 mm. and its shortest 1.5 mm. Above the oval window a well-marked

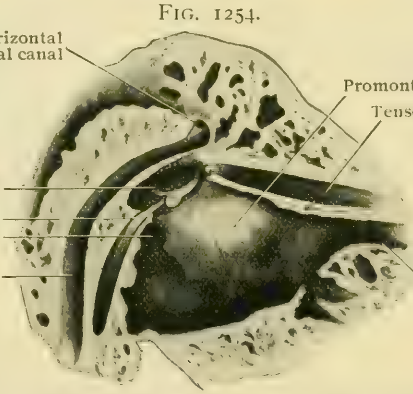
ridge indicates the position of the **facial canal** or *aqueductus Fallopii.* This ridge is bordered posteriorly and superiorly by the elevation which corresponds to the wall of the horizontal semicircular canal (**prominentia canalis semicircularis lateralis**). The **sinus tympani,** a well-marked depression, is behind the promontory, between the niche of the round window and the pyramid, below and behind the oval window. It is separated from the fossulæ of the two windows by bony ridges. It varies in depth from 2–5 mm., with a vertical diameter of from 2–6 mm.

The **superior wall** (**paries tegmentalis**) is formed by a plate of bone, the **tegmen tympani,** which forms part of the upper and anterior surface of the petrous portion of the temporal bone. Posteriorly it forms the roof of the antrum tympanicum, and anteriorly contributes the roof of the canal for the tensor tympani muscle and of the adjoining part of the Eustachian tube. It varies in thickness and may be defective to a large extent from atrophy or arrested development.

The **inferior wall** (**paries jugularis**), narrower than the superior, separates the typanum from the jugular fossa. Its bony plate may be incomplete and may lie considerably below the level of the membrana tympani.

The **anterior wall** (**paries carotica**) separates the tympanum from the carotid artery and at times presents a fissure. At its upper part is the irregular triangular opening of the Eustachian tube and above this opening lies the small canal for the

FIG. 1254.



Outer aspect of inner wall of right tympanic cavity; stapes lies within oval window. × 2½.

tensor tympani muscle. The canaliculus caroticus tympanicus perforates the anterior wall just below the mouth of the Eustachian tube, and transmits the tympanic branch of the internal carotid artery and carotico-tympanic nerves.

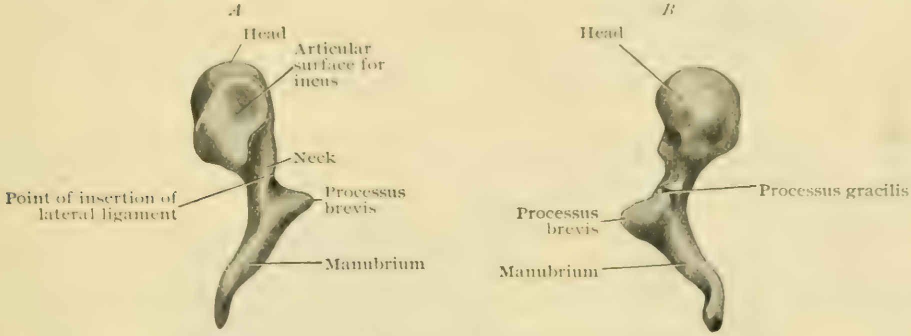
The **posterior wall** (**paries mastoidea**) of the tympanum at its upper part is occupied by the antrum tympanicum, which leads into numerous irregular cavities, the mastoid cells. At the lower border of the antrum is a saddle-shaped notch, the **fossa incudis,** which lodges the short process of the incus. Extending forward from the posterior wall, on a level with the lower border of the oval window, projects the small bony elevation, the **pyramid** (**eminentia pyramidalis**), which encloses the stapedius muscle (Fig. 1254). Its apex is pierced by a small round opening for the exit of the stapedius tendon. The canal within this eminence communicates posteriorly with the facial canal. On a level with the eminentia pyramidalis, close to the posterior margin of the drum-membrane, lies the **apertura tympanica canaliculi chordae tympani,** the opening through which the chorda tympani nerve enters the middle ear.

THE CONTENTS OF THE TYMPANUM.

The Auditory Ossicles.—Three small bones (**ossicula auditus**) form a chain extending across the upper part of the tympanum from the tympanic membrane to the labyrinth. The outermost of these, the *malleus* (hammer), is attached to the tympanic membrane; the innermost, the *stapes* (stirrup), is fixed in the oval window, and between these two bones and connected with both of them, lies the third link in the chain, the *incus* (anvil).

The **malleus** (hammer) is about 8 mm. long and consists of a head, a neck and three processes. The *head* is the upper club-shaped portion, lying in the epitympanic space; the constricted portion just below the head is the *neck*, and below this is a prominence to which the three processes are attached. The posterior surface of the head bears, for the articulation with the incus, an oblong depressed surface with prominent margins extending in a spiral manner downward and inward to the neck. This articular surface consists of two principal facets separated by an oblique ridge, the upper facet looking backward, the lower, inward. The axis of the head forms with that of the handle an angle of about 140°, opening upward and inward.

FIG. 1255.



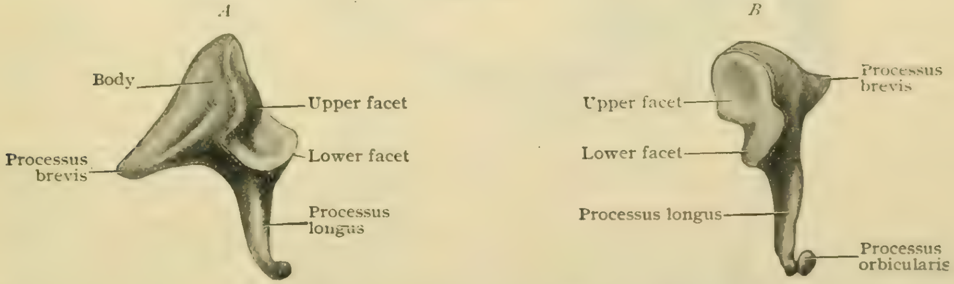
Right malleus; *A*, seen from behind; *B*, seen from in front. × 4½.

The *manubrium* (handle), a tapering process extending downward, backward and inward, is embedded in the substance of the tympanic membrane (Fig. 1258). Near the upper part of the inner anterior surface of the handle is sometimes found a slight projection for the insertion of the tensor tympani muscle. The lower end of the manubrium is spatula shaped, flattened transversely. The long process is directed toward the Glaserian fissure, whilst the short process looks toward the external meatus.

The *processus brevis* (short process) is a small conical elevation situated at the upper end of the handle, below the neck of the malleus. Like the handle it is attached to the tympanic membrane and covered by a layer of cartilage, notably on its external surface.

The *processus gracilis* (long process) arises from the anterior angle of the internal surface of the neck, close to the base of the short process, and extends downward and forward to the Glaserian fissure. It is well developed in the fœtus and in young children, but is often rudimentary in the adult.

FIG. 1256.

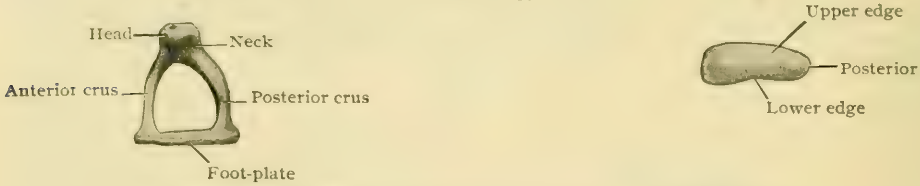


Right incus; *A*, lateral; *B*, anterior aspect. × 4½.

The **incus** (anvil) resembles a molar tooth with two widely separated fangs, rather than an anvil. It consists of a body, a long process and a short process. The *body* of the incus has two main facets on its anterior and antero-external surfaces, which correspond to those on the head of the malleus and articulate with them. The *processus brevis* (short process) is conical in shape, flattened laterally and projects nearly horizontally backward to a depression in the posterior wall of the tympanum at the entrance of the antrum, where its apex is attached. The *processus longus* (long process) runs downward and backward, behind and nearly parallel with the handle of the malleus, and forms nearly a right angle with the short process. At its lower end it is bent sharply inward and constricted into a neck, which terminates in a rounded tubercle, the *processus orbicularis*, that articulates with the head of the stapes. In the fœtus this process is separated from the rest of the long process.

The **stapes** (stirrup), as its name implies, is stirrup-shaped and consists of a head, neck, two crura and a base or foot-plate. The external surface of the small rounded *head* is hollowed out for articulation with the orbicular process of the incus. Just below this is the constricted *neck*, from which the two *crura* diverge to become attached to the foot-plate near its lower margin. The anterior crus is shorter and straighter than the posterior, both being slightly curved. The *foot-plate* consists of a lamina of bone and corresponds to the bean-shape of the oval window, into which it nearly fits. The upper edge of the foot-plate is convex ; its lower edge is almost straight, being slightly hollowed out near its middle.

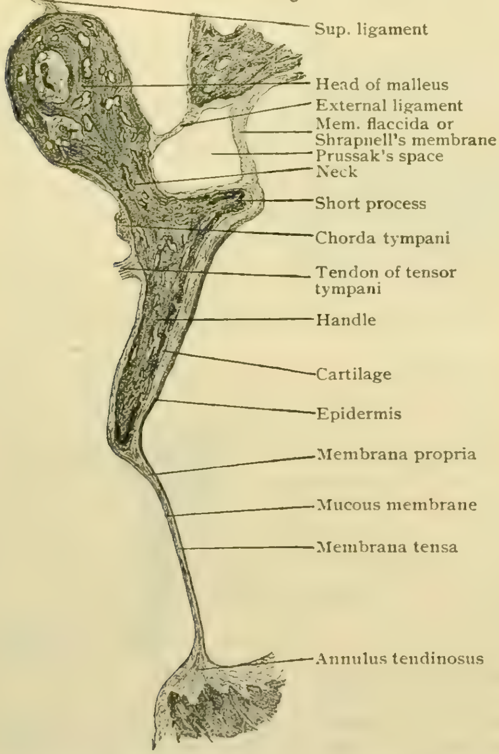
FIG. 1257.



Right stapes, *A*, seen from above; *B*, mesial surface of foot-plate. × 4½.

Articulations of the Ossicles.—In the **malleo-incudal joint**, both articular surfaces are covered with a thin layer of hyaline cartilage. The fairly well-developed capsular ligament, reinforced mesially, is fastened to the depressed margins of the articular surfaces. A wedge-shaped meniscus of fibro-cartilage projects from the upper wall of the capsule between the surfaces of hyaline cartilage. "When the manubrium handle moves inward, its lower cog catches the corresponding cog of the incus and the long process of the latter must follow. If the handle moves outward, the lower cog moves away from the incus and the latter moves but little" (Politzer).

FIG. 1258.



Frontal section passing through malleus and tympanic membrane. × 8. Drawn from preparation made by Dr. Ralph Butler.

The **articulation of the incus and stapes** is a very delicate but true joint. Both the slightly convex surface of the orbicular process of the incus and the slightly concave surface of the head of the stapes are covered with hyaline cartilage and united by a capsular ligament made up largely of elastic fibres and thickened on the posterior surface. Sometimes a meniscus of fibro-cartilage separates the two articular surfaces.

The **articulation of the stapes and oval window** is effected by the margins of the window and the foot-plate of the stapes. These surfaces, as well as the vestibular aspect of the stapes, are covered with a layer of hyaline cartilage. The cartilage of the foot-plate and that of the window are connected by a ligament of elastic fibres, forming a synchondrosis.

In addition to the ligaments concerned in the foregoing articulations, four bands attach the ossicles to the tympanic walls and prevent their excessive movement ; of these, three connect the malleus and one the incus.

1. The **superior ligament of the malleus** extends from the tegmen tympani to the head of the malleus. (Figs. 1252 and 1258.)

2. The **anterior ligament of the malleus** is a strong, broad, fibrous band arising from the anterior part of the head and neck of the malleus. Some of its fibres are attached to the anterior end of the annulus tympanicus (spina tympanica major) and other fibres pass through the Glaserian fissure to become attached to the spine of the sphenoid. These fibres correspond to the remains of the embryonic process of Meckel of the malleus and envelop the processus gracilis.

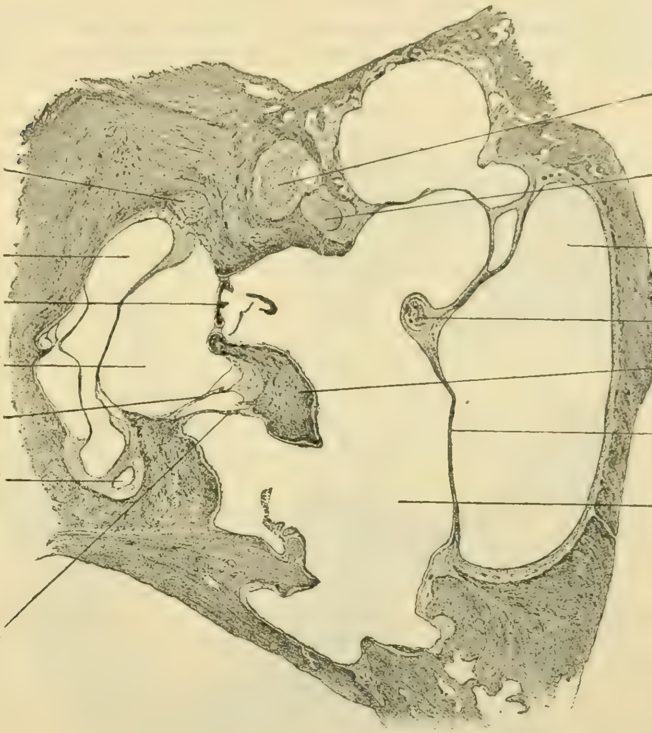
3. The **lateral ligament of the malleus** is somewhat fan-shaped and extends between the roughened neck of the malleus and the external wall of the tympanum above the Rivinian notch. The posterior fibres of this ligament are called the **posterior ligament** of the malleus (Helmholtz), and, together with the fibres of the anterior ligament lying in the same plane, form the "axis-ligament of the malleus," since the axis on which the malleus turns passes through the attachment of these two fibrous structures.

4. The **posterior ligament of the incus** extends from the apex of the short process of the incus to the tympanic wall at the lower part of the mouth of the antrum. It is fan-shaped, the incudal attachment being less extensive than that of the tympanic. The **superior ligament of the incus** is variable and consists chiefly of a fold of mucous membrane.

The Intratympanic Muscles.—The muscles within the tympanum connected with the ossicles (**musculi ossiculorum auditus**) are: (1) the *tensor tympani* and (2) the *stapedius*.

The **tensor tympani** is a diminutive spindle-shaped muscle, about 1.25 cm. long, lying in the bony canal directly above the osseous part of the Eustachian tube, from which it is partly

FIG. 1259.



Vertical section through human middle and internal ear. × 5½. Drawn from preparation made by Dr. Ralph Butler.

separated by the bony scroll, the *processus cochleariformis*. The posterior fibres arise from the top of the cartilage of the Eustachian tube and the adjoining part of the great wing of the sphenoid. Some of the fibres are connected with the tensor palati muscle and others arise from the wall of the canal which the muscle occupies. The fibres converge in a feather-like manner to the tendon, which begins within the muscle about the middle of the canal, and, passing through the tympanic opening of the canal, turns at nearly a right angle over the end or *rostrum* of the processus cochleariformis to be inserted into the anterior part of the inner margin of the malleus-handle just below the short process. The tendon is almost perpendicular to the plane of the tympanic membrane, is oblique to the long axis of the manubrium and is enveloped, along with the muscle-belly, in a fibrous sheath. The tensor tympani and tensor palati muscles receive their nerve supply from the same source, namely, the trigeminus, through the otic ganglion.

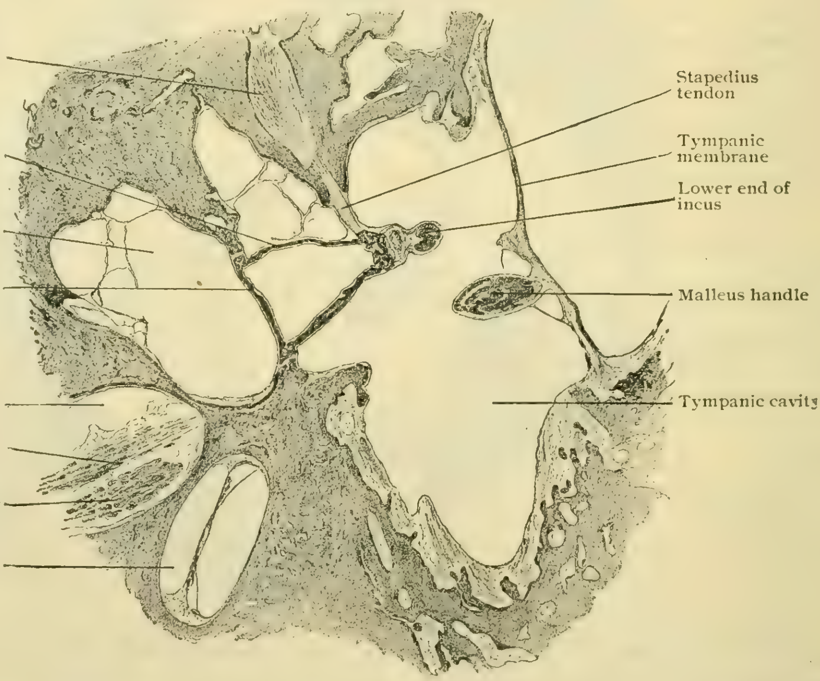
The **stapedius muscle** lies within the triangular canal of the eminentia pyramidalis, arising from its floor and sides. Its fibres converge to the tendon, which, passing through the opening at the apex of the canal, extends forward, slightly upward, and outward, to be inserted into the lower posterior part of the head of the stapes. Some of the fibres of the tendon also pass to the

orbicular process and the capsular ligament. The tendon is frequently enveloped in a fold of mucous membrane. A branch of the facial nerve passes through a small orifice between the Fallopian canal and the canal for the stapedius to supply this muscle.

Movements of the Ossicles.—When the tympanic membrane and malleus-handle are moved inward, the long process of the incus is also moved inward and pushes the head of the stapes inward, and slightly upward. This causes pressure upon the liquid within the labyrinth, and, since the bony walls of the labyrinth are inelastic, the membrane of the round window is bulged outward. As the tympanic membrane regains its normal position, these movements are reversed. When on the other hand the tympanic membrane is moved outward, the movement of the long process of the incus is very slight because of the unlocking of the malleo-incudal articulation. Contraction of the tensor tympani muscle draws the centre of the tympanic membrane inward and in this way increases the tension of the membrane and of the posterior part of the axial ligament of the malleus, especially of its external portion. Contraction of the stapedius muscle pulls the head of the stapes backward, thus tilting the anterior end of the foot-plate outward, the posterior end acting as a fulcrum.

The Mucous Membrane of the Tympanum.—The tympanic cavity is lined by a thin transparent mucous membrane, closely adherent to the periosteum and continuous with that of the Eustachian tube and naso-pharynx anteriorly, and

FIG. 1260.



Horizontal section through human middle and internal ear; stapes occludes oval window. × 5½. Drawn from preparation made by Dr. Ralph Butler.

with that of the mastoid cells posteriorly. It covers the ossicles and their ligaments, the muscles, the tendons and the chorda tympani nerve, and forms a number of folds extending across the cavity. These folds vary in location, direction and number, and form pouches within the tympanum.

The **attic** is divided into an external and an internal compartment by the incus, the head of the malleus, the superior ligament of the malleus and the superior malleo-incudal fold of mucous membrane. The external compartment is bounded on the outer side by the external tympanic wall, and is itself subdivided into a superior and an inferior space by the external ligament of the malleus. The inferior division is called **Prussak's space** and is bounded externally by Shrapnell's membrane, internally by the neck of the malleus, inferiorly by the short process of the hammer, and superiorly by the external ligament of the malleus (Fig. 1258). A number of

inconstant folds of mucous membrane extend from the wall of the tympanum to the malleus and the incus. The most constant of these is the outer malleo-incudal plica, which stretches backward to the posterior ligament of the incus. Additional folds frequently extend between the crura of the stapes and from these to the wall of the tympanum.

The **epithelium** of the tympanic mucosa varies in different parts of the cavity. Over the promontory, the ossicles and the tympanic membrane, it consists of a single layer of low cuboidal nonciliated cells, whilst over the other parts the cells are ciliated columnar in type. Small tubular glands occur within the lining of the anterior part of the cavity. The subepithelial connective tissue, which supports the vessels and nerves, comprises two layers, the outer forming the periosteum of the bony wall.

The **secondary tympanic membrane** closing the fenestra cochleæ, bulges somewhat toward the cochlea and is attached to the bony crest or ridge of the window by its widened rim. It consists of three layers, of which the middle one is a distinct fibrous lamina propria, which is covered on the tympanic surface by mucous membrane, and on the other side by an extension of the lining of the perilymphatic space. The lamina propria is composed of radially disposed bundles of fibrous tissue. The outer mucous stratum is formed of a thin fibrous tunica propria, invested by a single layer of flattened nonciliated epithelial cells, similar to those covering the neighboring promontory. The innermost stratum of the membrane includes a thin layer of subendothelial fibrous tissue, over which stretches a layer of endothelial plates.

Vessels and Nerves of the Tympanum.—The *arteries* supplying the tympanic cavity are from five sources.

1. The stylo-mastoid branch of the posterior auricular artery passes through the stylo-mastoid foramen and the Fallopian aqueduct, and sends a branch to the stapedius muscle and three branches to the posterior part of the tympanic cavity. One of these passes to the floor, one through the canal for the chorda tympani nerve, and one to the posterior part of the oval window.

2. The tympanic branch of the internal maxillary artery enters the tympanic cavity through the Glaserian fissure and supplies the anterior part of the cavity, including the anterior ligament of the malleus, the processus gracilis and the tympanic membrane.

3. The middle meningeal branch of the internal maxillary artery sends a branch through the hiatus Fallopii to anastomose with the stylo-mastoid artery, a branch through the canaliculus tympanicus to the promontory, and a branch to the tensor tympani muscle.

4. The ascending pharyngeal sends branches to the floor and the promontory, one of them accompanying Jacobson's nerve.

5. The internal carotid artery in its passage through the carotid canal gives off branches to the anterior wall of the tympanic cavity.

The *veins* follow, in a general way, the course of the arteries. They are tributary to the middle meningeal, the pharyngeal plexus and the jugulars.

The *lymphatics* arise from a net-work within the mucous membrane and end chiefly in the retropharyngeal and the parotid nodes.

The **nerves** supplying the mucous membrane of the tympanum are branches from the tympanic plexus formed by the tympanic branch of the glosso-pharyngeal nerve, in conjunction with sympathetic filaments from the net-work accompanying the carotid artery. The tensor tympani muscle receives its supply from the trigeminus; the stapedius muscle from the facial. Although the chorda tympani nerve has an intimate topographical relation to the space, which it traverses close to the outer wall, it gives no filaments to the structures within the tympanum.

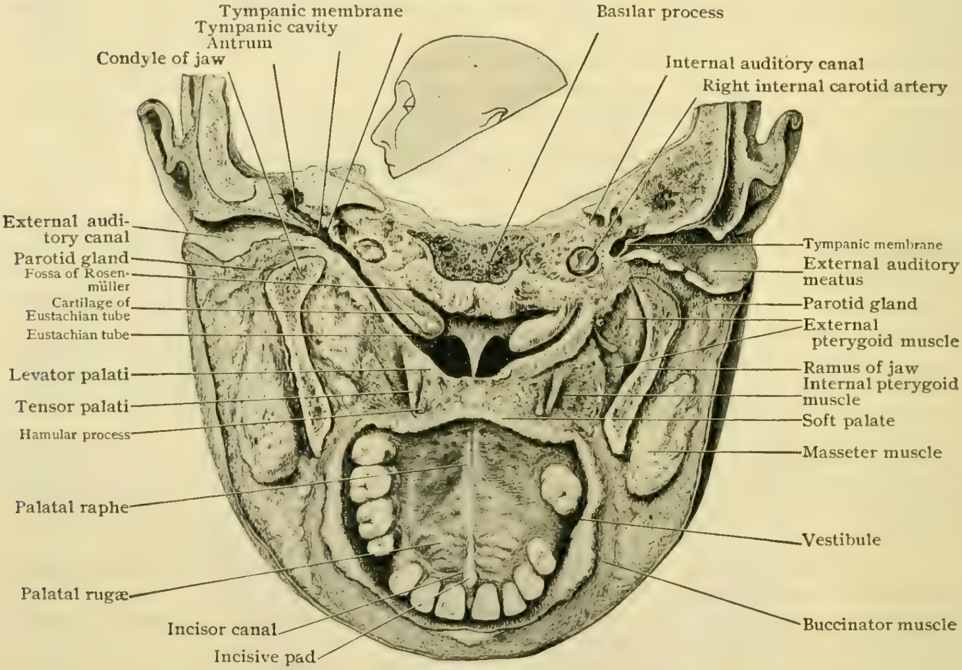
The Eustachian Tube.

The Eustachian tube (**tuba auditiva**) is a canal, partly bony and partly cartilaginous, extending from the lateral wall of the naso-pharynx backward, upward and outward to the anterior part of the tympanum. In the adult it measures about 37 mm. (1½ in.) in length, of which approximately the upper third (tympanic portion)

belongs to the bony division, whilst the remainder is contributed by the cartilaginous division of the tube. With the sagittal plane it forms an angle of 45°, and with the horizontal plane one of about 33°. With the long axis of the external auditory canal it forms an angle of from 135°–145°, opening outward. The cartilaginous and bony divisions of the tube do not lie exactly in the same plane, but join at a very obtuse angle opening outward. The tube has somewhat the shape of an hour glass, being wider at the ends and narrowed at the junction of the cartilaginous and bony portions into the **isthmus**, where its height is about 3 mm. and its breadth about half as much.

The **osseous** or **tympanic portion** (**pars ossea**) about 12 mm. long, is bounded above by the tegmen tympani and the canal for the tensor tympani muscle, from which it is incompletely separated by the processus cochleariformis. Below and internal to it lies the canal for the carotid artery. Its lumen is irregularly triangular in cross-section.

FIG. 1261.



Anterior part of section through head at plane shown in small outline figure, viewed from below; left Eustachian tube exposed throughout its length. Drawn from preparation made by Professor Dwight.

The **cartilaginous** or **pharyngeal portion** (**pars cartilaginea**) is about 25 mm. (1 in.) in length and attached to the rough oblique margin of the anterior end of the osseous portion of the tube.

Its posterior wall is formed by a plate of cartilage (**cartilago tubae auditivae**), the upper margin of which is curled outward upon itself to form a gutter, which appears on transverse section as a hook, whose inner and outer plates are known as the **mesial** and **lateral lamina** respectively. The interval between the margins of this cartilaginous groove presents outward and forward and is filled up with a strong fibrous membrane, thus completing the canal. Therefore part of the anterior wall and the posterior superior wall of the tube are formed by this cartilage and the rest of the anterior wall and all of the inferior by fibrous tissue. The cartilage is attached to the base of the skull and frequently is deficient in places, sometimes being divided into several pieces. At birth the cartilage is entirely of the hyaline variety, but later this is more or less extensively replaced, particulary in the pharyngeal division, by fibrocartilage, except in the upper part where the hyaline cartilage

persists. It is this cartilage, covered by the cushion of mucous membrane, that confers the characteristic Gothic arch contour to the lower opening, the **osteum pharyngeum**, of the tube.

The Mucous Membrane of the Eustachian Tube.—The Eustachian tube is lined throughout its length with mucous membrane, which differs somewhat in the cartilaginous and osseous portions. That in the former resembles the mucous membrane of the naso-pharynx, with which it is directly continuous, whilst that of the osseous division resembles, to some extent, the mucous membrane of the tympanic cavity. The *epithelium* of both divisions consists of the ciliated stratified columnar type, with some goblet cells, but the cells in the pharyngeal division, especially in the lower part, are taller than those of the tympanic portion, which are low cuboidal.

In the tympanic portion the mucous membrane is closely united with the periosteum and contains very few mucous glands and little or no adenoid tissue. In the cartilaginous division, on the contrary, the epithelium overlies a layer of adenoid

FIG. 1262.

Transverse section of cartilaginous Eustachian tube. × 7.

tissue, often called the **tubal tonsil.** This tissue is especially abundant in children, and beneath it are found numerous mucous glands which open on the free surface of the tube. These glands extend nearly to the perichondrium and sometimes can be traced even through the fissures in the cartilage into the surrounding connective tissue. A considerable amount of adipose tissue often occupies the submucosa of the lower and lateral walls. The submucous layer is well developed in the cartilaginous division of the tube, particularly in the outer membranous wall. It consists of loosely arranged fibro-elastic tissue, which supports the mucous glands and the larger vessels and nerves.

The **muscles** of the Eustachian tube are the *levator* and the *tensor palati*, the contractions of which not only affect the palate, but also produce changes in the position of the floor and in the lumen of the tube. These muscles are described in connection with the palate (page 1570), suffice it here to note their close relations to the Eustachian tube, beneath and to the inner side of which the levator lies, and to the outer side of which the tensor extends. By reason of the intimate attachment which both muscles have to the cartilage of the tube, since both take partial origin from this structure, contraction of their fibres tend to draw apart the walls of the canal and they thus serve as dilators. Such action is particularly true of the tensor palati, many of

whose fibres are inserted into fibrous tissue completing the lateral wall of the tube (Fig. 1262), this part of the muscle being designated the *dilator tubæ*. In addition to opening the tube, the levator palati elevates its floor.

The **blood-vessels** of the Eustachian tube include the *arteries*, which arise from the ascending pharyngeal and from the middle meningeal and the Vidian branches of the internal maxillary; and the *veins*, which communicate with those of the tympanum and of the pharynx and also form a plexus connecting with the cavernous sinus.

The **nerves** are supplied from the tympanic plexus and from the pharyngeal branches from the spheno-palatine ganglion.

The Mastoid Cells.

The antrum tympanicum communicates posteriorly with a variable number of irregular pneumatic cavities, the mastoid cells (**cellulae mastoideae**), so called because the majority of these spaces occupy the mastoid process. Unlike the antrum, these cells are not developed at birth. As the mastoid process develops, the original diploetic structure is usually more or less replaced by larger cavities forming the pneumatic type. In a study of one thousand bones, Randall found that scarcely two per cent. of mastoids could be classed as diploetic, and only some ten per cent. as combining a notable amount of diploë with pneumatic spaces; further, that no mastoid is absolutely pneumatic, although some senile bones show a single thin-walled cell occupying the greater part of the process. The pneumatic cells of this region may extend to the sigmoid portion of the lateral sinus; into the occipital bone; into the squamous portion of the temporal bone and above the external auditory canal; into the root of the zygomatic process; into the floor of the Eustachian tube close to the carotid canal, and occasionally as far as the apex of the petrous portion of temporal bone. These spaces are lined by a very thin mucous membrane, which is continuous with that of the antrum and of the tympanic cavity. It is closely united with the periosteum and possesses a layer of low nonciliated squamous epithelium.

The **blood-vessels** supplying the mastoid cells are the *arteries* derived from the stylo-mastoid and the middle meningeal, and the *veins*, which communicate with those of the tympanum and the external wall of the mastoid process. Some of the veins are tributary to the mastoid emissary and the lateral sinus, whilst others pass beneath the superior simicircular canal through the cranial wall to join the dural veins.

The **nerves** are the mastoid ramifications of the tympanic plexus.

Practical Considerations: The Tympanum.—This cavity is continuous anteriorly with the nasopharynx by way of the Eustachian tube, and posteriorly with the mastoid antrum and air cells by way of the attic, so that infection, which is very common in the pharynx, may extend throughout this whole tract. The tympanic cavity extends above the limits of the membrane about 5–6 mm. as the attic, and about 2–3 mm. below as the "cellar" or hypotympanic recess. Secretions on the floor, therefore, may not be seen through the membrane. The defective drainage which results from the lower level of the floor of the tympanum, as compared with that of the external meatus, is one of the causes of the frequency of chronic otitis media with purulent discharge, even after the early evacuation of the products of inflammation in the acute stage.

On the *internal wall* the *facial nerve* passes in a curve over the vestibule in the angle between the roof and inner wall of the tympanum, then downward in the slightly projecting Fallopian canal with a concave turn above and behind the oval window, continuing its course downward at the junction of the posterior and inner wall to emerge below from the skull at the stylo-mastoid foramen. This canal offers considerable resistance to caries in its immediate neighborhood, although the disease not infrequently communicates itself to the nerve. Such involvement of the nerve is often the prodromal symptom of a fatal cerebral affection (Politzer). At birth this portion of the Fallopian canal is very thin and translucent, and is deficient as it arches over the oval window, so that involvement of the nerve is much more common in children than in adults.

Roofing in the antrum and the passage leading into it from the attic is a thin layer of bone (tegmen antri), which is particularly thin over the antrum and separates these spaces from the middle fossa of the skull. Not infrequently there are membranous defects in the tegmen, upon which the dura rests (Macewen). Pus frequently passes through this bony plate, or its deficiencies, to the temporo-sphenoidal region of the brain, which is the most frequent seat of brain abscess.

Fractures of the base of the skull in the middle fossa may pass through the tegmen, rupturing the adherent dura, and permitting cerebro-spinal fluid to pass into the tympanum. If there is coincident rupture of the tympanic membrane, the fluid will likely appear at the external auditory meatus, or if the membrane remains intact, the fluid may pass to the pharynx through the Eustachian tube.

Often the hearing in chronic plastic otitis media is better during a great noise than when the surroundings are more quiet, because the stiffened ossicles transmit additional ordinary sounds more readily after they have been loosened by the more violent vibrations; or it may be because the auditory nerve, owing to the greater irritation, becomes more sensitive (Urbantschitsch).

The various relationships of the tympanum as involved in infectious disease should be understood from the standpoint of etiology and from that of sequelæ or complications.

Infection may reach the tympanum from (*a*) the naso-pharynx through the Eustachian tube (scarlatina, diphtheria, pharyngitis, tonsillitis, rhinitis); or (*b*) the mastoid antrum and cells posteriorly. It may extend from the tympanum (*a*) upward, by perforation of the tegmen, often deficient at places, leading to external pachymeningitis, or to subdural abscess; the dura, arachnoid, and pia mater at this level are fused, so that when the dura is ulcerated through, a diffuse meningeal infection does not ensue, but the process tends rather to spread into the brain along the perivascular lymphatic sheaths of the pial vessels, resulting in an abscess in the temporal lobe (Taylor); (*b*) to the internal jugular vein through venules that penetrate the fundus tympani to empty into the jugular bulb, and thence to the lateral sinus; (*c*) to the superior petrosal sinus and the dura mater of the middle fossa of the skull by the structures (veins and areolar tissue) passing through the petro-squamous suture; (*d*) to the facial canal either through congenital defects in its walls, or through carious openings, or along the course of the stylo-mastoid artery; facial paralysis may follow, or infection may travel along the internal auditory meatus and give rise to a diffuse leptomeningitis in the cerebellar fossa (Taylor); (*e*) to the labyrinth by way of the fenestra ovalis, or through the membrana tympani secondaria, which closes the fenestra rotunda opening into the scala tympani; permanent deafness may result from destruction of the labyrinth, and the infection may pass along the cochlear branch of the auditory nerve and the nerve itself to the cerebellar fossa; (*f*) to the ossicles causing caries and deafness; (*g*) to the mastoid antrum (*q.v.*).

The Tympanic Membrane.—The tympanic membrane is oblique in its lateral as well as in its vertical direction, so that the inferior wall of the auditory canal is longer than the superior, and the anterior wall longer than the posterior. The firm attachment of the handle of the malleus to the membrane causes it to assume the shape of a hollow cone with its convexity pointing internally. The innermost point of the cone is at the lower end of the handle of the malleus and is called the *umbo*. The distance between it and the promontory on the internal wall of the tympanic cavity is only about 2 mm.

Retention of the products of inflammation within the tympanum may decrease the inward bulging of the membrane or even cause it to protrude outward. When the Eustachian tube is obstructed, the air then confined within the middle ear, may become partly absorbed, allowing the external atmospheric pressure to increase the inward bulging, and to press the base of the stapes more firmly into the fenestra ovalis, giving rise to a ringing in the ears.

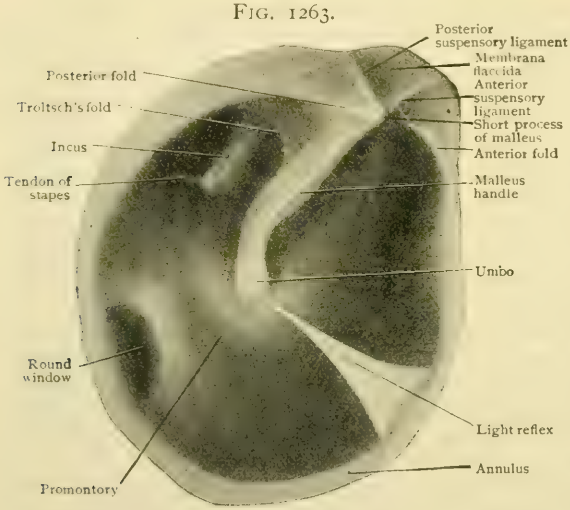
If an imaginary line in the axis of the handle of the malleus is continued to the lower margin of the membrane, and a second at right angles to this is carried through the *umbo*, the membrane will be divided by the vertical line into a lesser anterior and a greater posterior portion, and by the horizontal line into a greater upper and a lesser

lower portion, the umbo being slightly below the middle of the membrane. By the two lines the membrane is divided into unequal quadrants. This arrangement into quadrants is a very important one since the pathological appearances occurring in each differ greatly.

The *antero-superior* quadrant corresponds to the tympanic opening of the tube, the canal for the tensor tympani muscle, and the anterior pouch of the drum-head. The *antero-inferior* quadrant corresponds to the carotid canal. The *postero-superior* quadrant contains the long process of the incus, the stapes, and the articulations of these bones, the oval window, the pyramid, and stapedius muscle, the posterior pouch of the drum-head, the chorda tympani, and the posterior fold (pathologic). The *postero-inferior* quadrant contains the round window, the tympanic cells in the floor of the tympanic cavity and the bulb of the jugular vein. The flaccid portion or Shrapnell's membrane corresponds to the neck of the malleus and Prussak's space (Brühl-Politzer).

The bulb of the jugular vein may be larger than usual in which case it may encroach upon the posterior half of the membrane. Moreover, it may have an imperfect bony covering when it will be in danger during paracentesis tympani, the place of election of which is in this portion of the membrane. For the same reason, pus in the middle ear may more readily encroach upon the vein. The posterior inferior quadrant is selected for openings to evacuate effusions in the tympanum, because it is less sensitive and vascular than the rest of the membrane and corresponds to less important structures. The opening also gives better drainage than through any other portion. It should be borne in mind that the floor of the tympanum is 2–3 mm. below the inferior margin of the drum head, so that in the upright position perfect drainage cannot be obtained. The tympanic membrane has an internal mucous lining, an external cutaneous and an intervening fibrous layer. It, therefore, has little elasticity, so that, while small openings often heal rapidly, large openings close slowly, or not at all. A permanent opening, however, does not of necessity produce deafness.

FIG. 1263.



Normal drum-head of right side as seen with mirror. × 6.

With an aural speculum and good light, one may locate the various structures as follows : Above and in front is seen the short process of the malleus as an apparently prominent point. From this point two streaks pass to the periphery, showing the division between the tense portion of the membrane and its flaccid portion (Shrapnell's membrane), seen only in a roomy meatus. Extending backward and downward from this point is seen a whitish streak ending at the umbo. This is the long process or handle of the malleus. Directed downward and forward from the umbo is an area of light with its apex at the umbo and its base near the periphery of the membrane. It is triangular in shape and is due to the funnel shape of the membrane and the resulting light-reflex. Above and in front of the short process of the malleus is the membrane of Shrapnell. Through the grayish translucent tympanic membrane the contents of the tympanum may sometimes be seen, changing apparently the color of the membrane. Its conical shape has been proven by trial and mathematically to be the most favorable for the reception of sound waves. The vibrations are transmitted through the ossicles to the labyrinth by way of the oval window. The malleus rests in the membrane, the stapes occupies the oval window and the incus lies between and articulates with the two.

The Eustachian Tube.—The superior orifice of the Eustachian tube is in the upper part of the anterior wall of the tympanum, and is therefore, not well adapted for drainage of that cavity. The tube is directed downward, forward, and inward to the side of the naso-pharynx, where it is on a level with the posterior end of the inferior turbinate bone. In children it is wider, shorter, and more horizontal, so that in infection of the middle ear drainage in them is better, but, for the same anatomical reasons, otitis media is more likely to follow pharyngeal and tonsillar infections. The pharyngeal orifice is bounded above and at the inner side by the prominent cartilaginous arch which encloses a funnel-shaped opening. The mucous membrane over this projection is thickened by a cushion of adenoid tissue, hypertrophy of which is frequently associated with pharyngeal adenoids and enlarged tonsils, and may occlude the tube, ultimately causing deafness. The upper border of the pharyngeal opening of the tube is a half inch above the soft palate, and the same distance below the basilar process, below the hinder end of the inferior turbinate bone and in front of the posterior pharyngeal wall (Tillaux). Immediately behind this orifice is the well-marked depression called Rosenmüller's fossa, the depth of which is increased in cases of enlargement of the pharyngeal tonsil and which may then lead to difficulty in the passage of a catheter into the Eustachian tube. It may also, when recognized, serve as a useful guide to the orifice of the tube. Injury to the orifice of the tube during operations in the naso-pharynx, or at the posterior ends of the turbinates, may lead to cicatricial contraction and occlusion, thus causing defective hearing. Ulcerations in the naso-pharynx may produce a like effect. The length of the tube is about 37 mm. (1½ in.) and its pharyngeal opening is about 25 mm. (1 in.) lower than the tympanic. Its upper third (12 mm.) is bony, and its lower two-thirds (25 mm.) cartilaginous. The narrowest part, the isthmus, is at the junction of these two portions. The lumen of the cartilaginous portion forms a somewhat S-shaped slit, the walls being in actual contact, except during the act of swallowing, when the slit opens so that air may reach the tympanum and equalize the atmospheric pressure on the two sides of the tympanic membrane. In the bony portion, though the lumen is smaller, it is open. In cases of obstruction of the tube at its pharyngeal end—as by pressure from a growth, or from a thickened mucosa—the outside pressure predominates, the tympanic membrane is pushed inward, and buzzing or "singing in the ears" results. Whenever the palate is raised or deglutition takes place, the tensor palati and levator palati contract, and in so doing open the Eustachian tube by traction on the fibrous tissue which unites the outer borders of the fibro-cartilaginous scroll of which the tube is composed. Concussion of the tympanic membrane from loud reports, as from the firing of great guns, is minimized by breathing with the mouth open, thus elevating the soft palate, opening the Eustachian tube, and equalizing the pressure on the two sides of the membrane.

Inflation of the *tympanum* is accomplished through the Eustachian tube, and is employed for diagnostic, prognostic, and therapeutic purposes. Several methods are in use. Valsalva's consists of a vigorous expiratory effort while the nose and mouth are kept closed. Politzer inflates the tympanum through one nostril by a vigorous compression of a rubber air-bag, while the patient is in the act of swallowing. The opposite nostril and mouth are closed. The most satisfactory method in difficult cases is by means of the Eustachian catheter. The instrument is passed tip downward along the floor of the nose until it drops into the post-nasal space and the posterior wall of the pharynx is reached. The tip is then turned gently outward and withdrawn about 1 cm. when the slight resistance of the cartilaginous rim is felt. After gliding forward over this prominence, it will engage in the orifice of the tube. The ring at the proximal end of the catheter—which is in the plane of the the curve of the beak and thus shows the position of the latter—is then directed toward the external meatus of the same side (Bonnafont). The catheter may be withdrawn, and the tip at the same time be turned to the opposite side from the one to be catheterized, so that the beak of the instrument catches on the edge of the vomer. It is then turned upward through 180°, and thus enters the tubal opening (Frank, Löwenberg).

Foreign bodies may lodge in the tube during vomiting, or a broken piece of the bougie may be left in. They will usually escape during vomiting or hawking, or they may be removed by an instrument if visible.

If the tube is normal, a bougie 1½ mm. in diameter will easily pass the isthmus, the narrowest part. Strictures may be dilated or applications made by bougies. Narrowing of the lumen may occur near the isthmus from chronic inflammation or, at the pharyngeal orifice, from the pressure of pharyngeal adenoids, tumors, or polypi.

Mastoid Process and Cells.—The mastoid process which is formed by the posterior extremity of the petrous bone, is relatively small at birth and contains no air cells except the antrum. The *antrum* is almost constant, although its size varies. In the infant it will hold a small pea, while in the adult its average length is from 12–15 mm. (one-half inch or slightly more), its height 8–10 mm., and its width about 7 mm. (Brühl). It is the means of communication between the tympanum and the mastoid cells, so that infection finds an easy passage from the former to the latter. Its distance from the external surface of the mastoid process will depend upon the size of its cavity. This is usually from 12–14 mm. Anteriorly the antrum opens into the attic portion of the tympanum, and is in almost a direct line through that cavity with the Eustachian tube. A probe passed up the tube from the pharynx would pass through the attic into the antrum and would strike the joint between the incus and the stapes. The axis of the external canal would strike the line at an angle of about thirty degrees.

The floor of the antrum is below the level of the entrance into the attic, so that pus in the antrum tends rather to enter the mastoid cells. Sometimes nearly all the mastoid cells are pneumatic ; more frequently they are diploetic at the tip of the mastoid process, and pneumatic above (page 184). Pus in the air spaces may reach the diploetic region by breaking down the thin intervening septa. Those cases in which there are no mastoid spaces are probably sclerotic from pathological causes. Thus a chronic inflammation of the mastoid may give rise to new bone formation, filling the diploë and causing eburnation. This would tend to prevent the outward progress of pus and would favor its extension toward the interior of the cranium.

The **suprameatal spine** is about 10–12 mm. above the floor of the antrum, which corresponds to a point about half way up the posterior wall of the bony meatus, and lies about 5 mm. posterior to the inner end. Thus bulging of the posterior wall of the meatus may result from disease in the antrum. The squamo-mastoid suture is frequently seen on the surface of the mastoid process in children, and may give passage to pus from the antrum to the surface. Through deficiencies in the mastoid process near its tip pus may find its way into the sheath of the sterno-cleido-mastoid muscle, or along the large blood-vessels into the neck.

The bony wall between the antrum and posterior fossa of the skull is thin and cancellous, and may show deficiencies through which pus may reach the posterior fossa. In the fossa on the posterior surface of the mastoid process is the groove for the sigmoid sinus, which is frequently infected from disease of the antrum. Such infection may extend from the antrum to the posterior or cerebellar fossa of the skull, causing meningitis, septic thrombus of the lateral sinus, or a subdural or cerebellar abscess.

The possible lines of extension of mastoid inflammation may be summarized as follows (after Taylor) : (1) *Upward*, from absorption of the thin tegmen antri, or through the veins passing up through foramina in the tegmen (causing external pachymeningitis in the floor of the middle cranial fossa), or through the remains of the petro-squamous suture (causing thrombosis of the superior petrosal sinus). (2) *Downward*, by emissary veins, or through a sinus at the lower part of the mastoid in the digastric fossa (causing cellulitis beneath the sterno-mastoid, or travelling along the stylo-glossus, stylo-pharyngeus and stylo-hyoid to the retro-pharyngeal region). (3) *Forward*, through the thin bony layer separating the external auditory meatus from the antrum and the mastoid cells (causing discharge from the meatus if the perforation is complete, or if it remains subperiosteal, directing the pus outward to a point just back of the pinna). (4) *Outward*—especially in children—through the thin post-auditory process of the squamous bone, or through the open masto-

squamous suture (causing a fluctuating adenomatous postauricular swelling, pushing the pinna forward and making it unduly prominent). (5) *Inward*, either through venules passing to the sigmoid sinus, or through caries of the wall of the sigmoid groove (causing external pachymeningitis, or subdural abscess, or suppurative basal meningitis, or cerebellar abscess—by way of the cerebellar veins emptying into the lateral sinus—or, most frequently, sigmoid sinus thrombosis).

The **sigmoid sinus** is usually about 1 cm. behind the suprameatal spine, but is occasionally so far forward as to lie just beneath the external surface of the mastoid process, and immediately behind the bony wall of the meatus.

Owing to its close relation to the mastoid antrum and cells, no other cranial sinus is so frequently the seat of infective inflammation. In infants, however, it is seldom seen, owing to the following facts: First, the mastoid cells are not developed in them, though the antrum exists; secondly, the squamous covering of the antrum is not yet soldered to the mastoid, and therefore, purulent matter finds a ready exit, not being enclosed in a complete bony casing; thirdly, more numerous exits for the venous blood exist in infants than in adults; and fourthly, the sigmoid sinus rests on a flatter osseous surface than in adults, the bony gutter which imbeds the adult sinus being not yet fully formed. In infants the internal ear is more exposed than in adults to pathological encroachments from the middle ear, hence in them leptomeningitis is apt to ensue, which frequently ends fatally, and that so rapidly as to prevent the formation of sigmoid sinus thrombosis (Macewen).

When the sigmoid sinus is infected, extension may occur to the venous channels associated with it, especially to the internal jugular, anterior condylar, and deep veins of the neck into which the anterior condylar empty themselves. Evidence of involvement of these may be found in two areas,—along the internal jugular, and in the upper third of the posterior cervical triangle. Pain on pressure over the inflamed veins may be elicited even when the patient is deeply somnolent or semi-conscious. Thrombosis of the internal jugular when marked, is very easy of detection, as it lies so superficially. The finger perceives a cord-like formation to the inner side of the sterno-mastoid on the outer side of the artery, though the latter is sometimes overlapped by it. This may extend the whole length of the internal jugular, but it is frequently confined to the upper third. The entire thrombus may be disintegrated and its particles carried by the current to the lung, where they may set up infective infarction. They may be carried to the lungs by the veins passing into the posterior cervical triangle which flow through the vertebral and other channels to the subclavian (Macewen).

The complication most to be feared in middle ear disease is the spread of the infection to the interior of the cranium. This may occur by direct extension of the carious process through the bone; more rarely through the labyrinth and internal auditory canal or the aqueducts; or, still more rarely along the small blood-vessels or connective tissue fibres which pass through the bone between the middle ear and the dura. Very exceptionally the pus may find its way through the thin anterior wall into the carotid canal and along this to the cranial cavity.

Although otitis media appears to occur on both sides with equal frequency, the right side of the head has been said to be more frequently affected by intracranial sequelæ. If so, this is probably due to the greater size of the lateral sinus and the sigmoid sinus on the right side. Consequently the right sigmoid sinus encroaches more upon the petrous and the mastoid portions of the temporal bone, especially at the sigmoid knee, and the distance between the lower border of the tympanum and the antrum on the one hand and the sigmoid sinus on the other, is less than between the corresponding points on the left side (Macewen).

Involvement of the internal ear from otitis media is comparatively rare. This portion of the ear is developed independently of the rest, and, after necrosis, may be extruded in sequestræ, in which may be recognized the structure of the labyrinth. If the pus associated fails to escape externally, there is danger of its passing through the internal auditory meatus and aquæductus vestibuli to the brain. Affections of the semi-circular canals produce disturbances of equilibrium.

The sinus is in danger in operations on the antrum, the external opening for which should be immediately behind the meatus, and the centre of the opening 2–3

mm. below the level of its upper wall. If the sinus is in an abnormally anterior position, the posterior wall of the meatus must be removed to gain more room.

The **facial nerve** is also in great danger in these operations, and has frequently been injured. It lies in the inner wall of the mouth of the antrum, and is therefore, in front of it. The antrum is approximately about 12 mm. (one-half inch) in a direction very slightly inward, forward, and upward from a point on the external surface, 5 mm. posterior to the suprameatal spine. The anterior edge of the opening made to reach the antrum should be at this point, and its upper edge 3 mm. below the spine. It should never be carried deeper than 1½ cm. (⅝ in.) from the anterior edge of the external opening, for fear of injuring the facial nerve or external semicircular canal.

As the situation of the mastoid antrum is the key to the position in all operations upon either the antrum itself or the mastoid cells, Macewen has noted three points in the anatomy of the mastoid that may govern the surgeon in reaching the antrum without (*a*) opening the sigmoid groove and injuring its enclosed sinus; (*b*) encroaching upon the Fallopian canal and destroying the facial nerve; (*c*) invading the middle cerebral fossa; (*d*) injuring the semicircular canals.

1. The **suprameatal triangle**—the lower border of which corresponds with the level of the roof of the antrum, and is, therefore, a few lines below the level of the base of the temporo-sphenoidal lobe—is bounded above by the posterior root of the zygoma, below by the postero-superior segment of the bony external meatus, and behind by a line uniting these two and drawn vertically from the posterior border of the meatus to the zygomatic root. The opening is made within this triangle and close to the last line—the base of the triangle.

2. The excavation of the bone is carried inward and a little forward, in the direction of the posterior wall of the bony meatus, as shown by a probe passed into it from behind between the skin and the osseous wall. The more oblique the direction of this wall from behind forward, the more anterior the situation of the antrum.

3. The depth of the inner wall of the tympanic cavity from the level of the skull at the bony external meatus should be determined by introducing a probe through the external ear (and through the tympanic membrane previously perforated by pathological processes) until it touches the inner wall of the tympanum. If this cavity lies deeply, the more superficial mastoid antrum will be relatively deep also.

Of forty brain abscesses, the bone was diseased directly to the dura in thirty-seven (92 per cent.), the bone was diseased, but not the dura, in one (2.5 per cent.), and the bone was healthy in two (5 per cent.) (Körner).

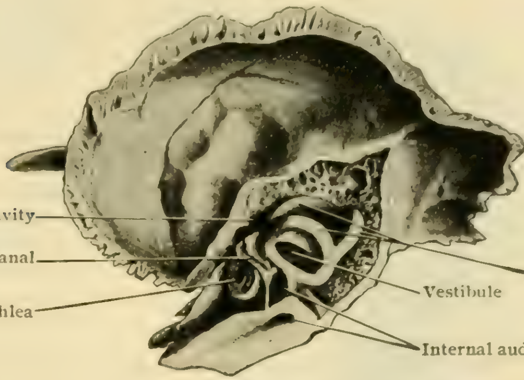
It follows from this list of cases, that after a thorough exposure of the antrum and the ear cavities, the carious process should be followed inward to the dura or brain. In case an abscess in the temporo-sphenoidal lobe cannot be reached in this way the skull may be opened by a trephine, or by an osteo-plastic resection immediately above the ear. A cerebellar abscess might be reached by an opening one and one-half inches behind the centre of the bony meatus and one inch below Reid's base line.

THE INTERNAL EAR.

The internal ear consists essentially of a highly complex membranous sac, connected with the peripheral ramifications of the auditory nerve, and a bony capsule, which encloses all parts of the membranous structure and is embedded within the substance of the petrous portion of the temporal bone. These two parts, known respectively as the *membranous* and the *bony labyrinth*, are not everywhere in close apposition, but in most places are separated by an intervening space filled with a fluid, the *perilymph*, the inner sac lying within the osseous capsule like a shrunken cast within a mould. The membranous labyrinth is hollow and everywhere filled with a fluid, called the *endolymph*, which nowhere gains access to the cavity occupied by the perilymph. The internal ear is closely related, on the one side, with the bottom of the internal auditory canal, which its inner wall contributes, and with the inner wall of the tympanic cavity on the other. Its entire length is about 20 mm., and its long axis corresponds closely with that of the pyramidal or petrous

portion of the temporal bone. The position of approximately its posterior third is indicated by the transverse ridge that crosses the upper surface of the temporal bone a short distance behind the internal auditory meatus. The irregular cavity of the bony labyrinth, hollowed out in the temporal bone, comprises three subdivis-

FIG. 1264.



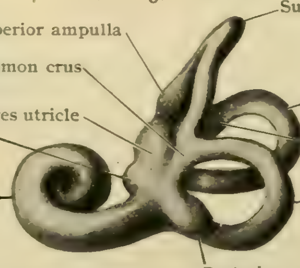
Right temporal bone, upper part of petrous portion has been removed to show bony labyrinth lying in position.

ions :—a middle one, the *vestibule*, an anterior one, the *cochlea*, and a posterior one, the *semicircular canals*. Both the front and hind divisions communicate freely with the vestibule, but neither communicates with the membranous labyrinth nor, in the recent condition, with the tympanic cavity. Although corresponding in its general form with the bony compartments of the cochlea and semicircular canals, the membranous labyrinth less accurately agrees in its contour with the bony vestibule, since, instead of presenting a single cavity, it is subdivided into two unequal compartments, known as the saccule and the utricle, which are lodged within the bony vestibule. The divisions of the membranous labyrinth are, therefore, four, which from before backward are : the *membranous cochlea*, the *saccule*, the *utricle* and the *membranous semicircular canals*.

The Osseous Labyrinth.

The Vestibule.—The vestibule (**vestibulum**), the middle division of the bony labyrinth, lies between the cochlea in front and the semicircular canals behind and communicates freely with both. It is an irregularly elliptical cavity, measuring about 5 mm. from before backward, the same from above downward, and from 3–4 mm. from without inward. The lateral (outer) wall separates it from the tympanic cavity, and contains the oval window with the foot-plate of the stapes. The medial (inner) wall, directed toward the bottom of the internal auditory canal, presents two depressions separated by a ridge, the **crista vestibuli**, the upper pointed end of which forms the **pyramidalis vestibuli.** The anterior and smaller of these depressions is the **spherical recess** (**recessus sphaericus**) and lodges the saccule. In the lower part of this fossa, about a dozen minute perforations mark the position of the **macula cribrosa media** for the passage of branches of the vestibular nerve from the bottom of the internal auditory canal to the saccule. The posterior and larger depression is the **elliptical recess** (**recessus ellipticus**). Behind the lower

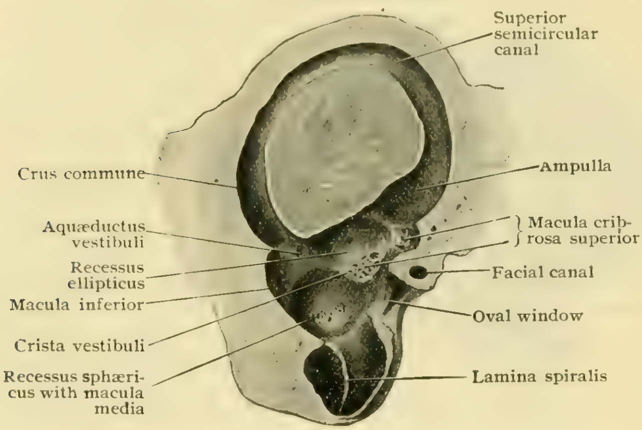
FIG. 1265.



Cast of right bony labyrinth, mesial aspect. × 2.

part of the spherical recess, the crista vestibuli divides into two limbs between which is the **recessus cochlearis**, which lodges the beginning of the ductus cochlearis and is pierced by a number of small openings for the passage of nerve filaments to this duct. The numerous minute holes piercing the crista (pyramid) and the elliptical recess collectively form the **macula cribrosa superior** (Fig. 1266) and transmit branches of the vestibular nerve to the utricle and to the ampullæ of the superior and horizontal semicircular canals. Below and behind the recessus ellipticus lies a groove, the **fossula sulciformis**, which deepens posteriorly into a very small canal, the **aqueduct of the vestibule** (**aquaeductus vestibuli**) which runs in a slightly curved course to the posterior surface of the petrous portion of the temporal bone, where it ends in a slit-like opening, the **apertura externa aquaeductus vestibuli**, situated between the internal opening of the internal auditory canal and the groove for the lateral sinus. The canal transmits the ductus endolymphaticus and a small vein. The anterior wall of the vestibule is pierced by the large opening leading into the scala vestibuli of the cochlea. Near this aperture is seen the beginning of the lamina spiralis ossea which lies on the floor of the vestibule below the oval window. Posteriorly the vestibule directly communicates with the semicircular canals by five round openings.

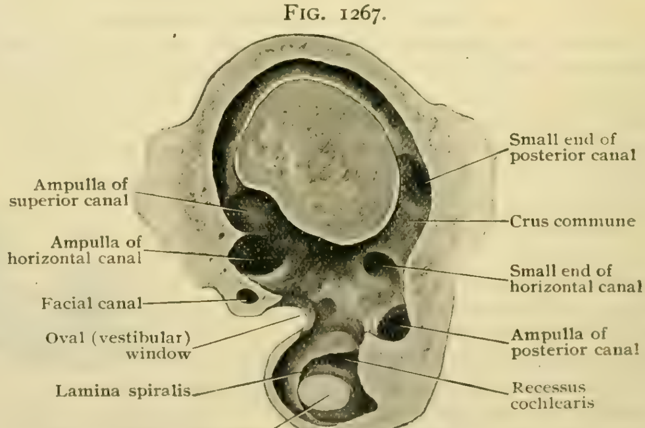
Fig 1266.



Section of right bony labyrinth passing through plane of superior semicircular canal; anterior wall of vestibule is seen from behind. × 4.

The Semicircular Canals.—The three bony semicircular canals—the *superior*, the *posterior* and the *horizontal*—lie behind the vestibule and are perpendicular to one another (Fig. 1265). Their disposition is such that the planes of the three canals correspond with the sides of the corner of a cube, suggestively recalling the relations of the three cardinal planes of the body—the sagittal, frontal and transverse. Each canal possesses at one end a dilatation, called the **osseus ampulla**. The **superior canal** (**canalis superior**) lies farthest front and in a nearly vertical plane at right angles to the long axis of the petrous portion of the temporal bone, whilst the plane of the longest canal, the **posterior** (**canalis posterior**) is approximately parallel to it. The external portion of the horizontal semicircular canal forms a prominence on the inner wall of the middle ear above the facial canal, while the upper part of the superior semicircular canal produces the conspicuous elevation, the eminentia arcuata, seen on the superior

Fig. 1267.

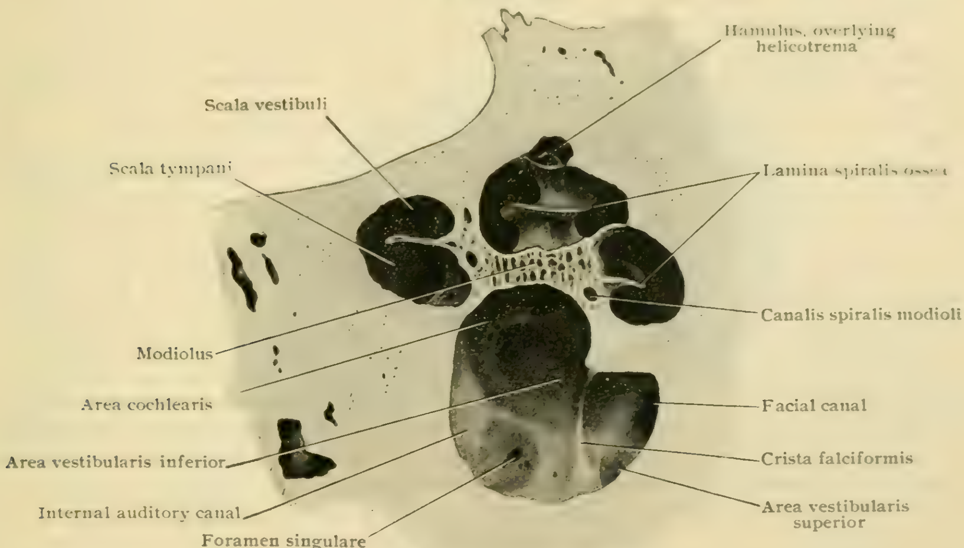


Section of right bony labyrinth passing through plane of superior semicircular canal; posterior wall of vestibule is seen from before. × 4.

surface of the petrous bone. The semicircular canals open into the posterior part of the vestibule by five apertures (Fig. 1267), the undilated ends of the superior and posterior canals joining to form a common limb (**crus commune**). The **horizontal canal** (**canalis lateralis**) alone communicates with the vestibule by two distinct openings. Its ampulla is at its outer end and lies at the upper part of the vestibule above the oval window, from which it is separated by a groove corresponding to the facial canal. Lying above and close to this opening is placed the ampullary end of the superior canal. The ampullary end of the posterior canal lies on the floor of the vestibule, near the opening of the non-dilated end of the horizontal canal and of the canalis communis. In the wall of the ampulla of the posterior canal, a number of small openings (**macula cribrosa inferior**) provide for the entrance of the special branch of the vestibular nerve destined for this tube.

The Cochlea.—The bony cochlea constitutes the anterior part of the labyrinth and appears as a short blunt cone, about 5 mm. in height, whose base forms the anterior wall of the outer end of the internal auditory meatus. Its apex is directed hori-

FIG. 1268.



Cochlea and bottom of internal auditory canal exposed by vertical section passing parallel with zygoma; preparation has been turned so that cochlea rests with its base downward and apex pointing upward. × 5.

zontally outward, somewhat forward and downward, and reaches almost to the Eustachian tube. Its large lower turn bulges into the tympanic cavity and produces the conspicuous elevation of the promontory seen on the inner wall of the middle ear (Fig. 1269). The bony cochlea consists essentially of a tapering central column, the **modiolus**, around which the bony canal, about 30 mm. long, makes something more than two and a half spiral turns, the *basal*, *middle* and *apical*. The conical modiolus has a broad concave **base** which forms part of the base of the cochlea (**basis cochlea**), and a small **apex** which extends nearly to the apex of the cochlea, or **cupola** (**cupula**). It is much thicker within the lowest turn of the canal than above, and is pierced by many small canals for the nerves and vessels to the spiral lamina (Fig. 1268). The axis of the modiolus, from base to apex, is traversed by the **central canal**, whilst a more peripherally situated channel, the **canalis spiralis**, encircles the modiolus and contains the spiral ganglion and a spiral vein. Projecting at a right angle from the modiolus into the canal of the bony cochlea is a thin shelf of bone, the **lamina spiralis ossea**, which is made up of two delicate bony plates between which are fine canals containing the branches of the cochlear nerve. The spiral lamina begins between the round window and the lower wall of the

vestibule (Fig. 1269), and after winding spirally around the modiolus to the apex of the cochlea, ends in a hook-like process, the **hamulus**, which forms part of the the boundary of the helicotrema (Fig. 1269). The partial division of the canal of the bony cochlea effected by the osseous spiral lamina is completed by the **membranous spiral lamina**, which stretches from the free edge of the osseous lamina, to which it is attached, to the outer wall of the canal (Fig. 1271). The upper division of the canal is called the **scala vestibuli** and communicates with the vestibule, whilst the lower division, the **scala tympani**, would open into the tympanic cavity, were it not separated from that space by the secondary tympanic membrane. These scalæ communicate with each other through an opening, the **helicotrema**, at the apex of the cochlea. Close to the beginning of the scala tympani at the round window is the inner orifice of the **aquæductus cochleæ** (**ductus perilymphaticus**), its outer opening being in a depression on the lower surface of the pyramid near its posterior edge. It transmits a small vein and establishes a communication between the subarachnoid space and the scala tympani.

The **internal auditory canal** communicates with the cranial cavity by an oval opening on the posterior surface of the pyramidal portion of the temporal bone, from which it extends outward to the internal ear. Its outer or lateral end, the **fundus**, is divided into a smaller superior and a larger inferior fossa by a transverse ridge, the **crista falciformis**. In the anterior part of the superior fossa (**area facialis**) is the opening of the **facial canal** (**aquaeductus Fallopii**) for the transmission of the facial nerve. In its posterior part are the openings (**area vestibularis superior**) for the branches of the vestibular nerves which supply the utricle and the ampullæ of the superior and horizontal semicircular canals. These openings appear in the macula cribrosa superior on the inner surface of the bony labyrinth (page 1512). The anterior part of the inferior fossa is called the **area cochlearis** and is perforated about its middle by the opening of the central canal of the modiolus. Surrounding this are the numerous small apertures of the **tractus spiralis foraminosus** for the transmission of branches of the cochlear nerve to the two lower turns of the cochlea. Behind the area cochlearis and separated from it by a ridge, lies the inferior area of the vestibule (**area vestibularis inferior**) with its small openings for the passage of nerves to the saccule. The macula cribrosa media, described above, is formed by these openings. Behind the inferior fossa is a large opening, the **foramen singulare**, which leads into a canal at the other end of which are the small openings of the macula cribrosa inferior. It transmits the branch of the vestibular nerve destined for the ampulla of the posterior semicircular canal.

The Membranous Labyrinth.

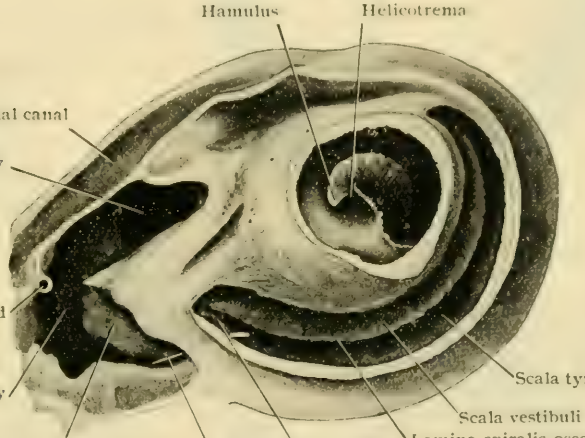
The membranous labyrinth (**labyrinthus membranaceus**) lies within the bony labyrinth, which it resembles in general form. This agreement is least marked within the vestibule, since here the single division of the bony capsule is occupied by two compartments of the membranous sac, the utricle and the saccule. The membranous labyrinth comprises: (1) the *utricle* and the *saccule*, which, with the *ductus endolymphaticus*, lie within the vestibule; (2) the three *membranous semicircular canals* lodged within the bony semicircular canals; and (3) the *membranous cochlea* enclosed within the bony cochlea. The membranous labyrinth is attached, especially in certain places, by connective tissue to the inner wall of the bony capsule. The interval between the membranous and bony labyrinths, largest in the scalæ tympani and vestibuli of the cochlea and in the vestibule, constitutes the perilymphatic space (**spatium perilymphaticum**) and contains a modified lymphatic fluid, the **perilymph**. The fluid within the membranous labyrinth, appropriately called the **endolymph**, can pass from one part of the labyrinth to another, although the saccule and utricule are only indirectly connected through the **ductus endolymphaticus** and a narrow channel, the **canalis utriculo-saccularis**.

The Utricle.—The utricle (**utriculus**) occupies the recessus ellipticus in the upper back part of the vestibule. It is larger than the saccule and communicates with the three membranous semicircular canals. Attached to the upper and inner walls of the vestibule by connective tissue, it extends from the roof of the vestibule

backward and downward to the opening of the posterior ampulla, a distance of from 5.5–6 mm. The utricle is made up of three subdivisions, the uppermost of which is respresented by a blind sac, from 3–3.5 mm. in length and breadth, called the **recessus utriculi**, whilst the two lower divisions together form the **utriculus proprius**, which measures 3 mm. by from 1.5–2 mm. The lower part of the utricle proper is prolonged into the tube-shaped **sinus posterior**, which connects the ampulla of the posterior semicircular canal with the utricle.

The **openings of the semicircular canals** into the utricle are disposed as follows: *into the recessus utriculi* open (1) the ampulla of the superior semicircular canal and (2) that of the horizontal canal. *Into the utriculus proprius* open (3) the sinus superior, which lies within the crus commune and receives in turn the nonampullated ends of the superior and posterior semicircular canals; (4) the nonampullated end of the horizontal semicircular canal; and (5) the ampulla of the posterior semicircular canal through the sinus posterior. On the antero-lateral wall of the recessus utriculi is placed the macula acustica of the utricle, whilst from its

FIG. 1269.



Right bony cochlea partially exposed by section passing through outer wall of apex and of first turn.

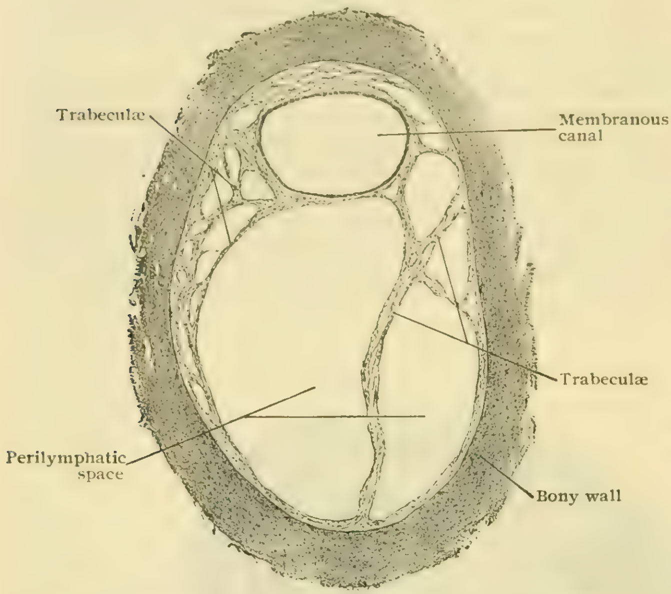
antero-mesial wall springs the canalis utriculo-saccularis, the small canal from the utricle that joins even a smaller passage from the saccule to form the ductus endolymphaticus.

The Saccule.—The saccule (**sacculus**) is an irregularly oval compartment, about 3 by 2 mm. in size, which occupies the recessus sphæricus in the lower and anterior part of the vestibule, to which it is attached by connective tissue. It is somewhat flattened laterally and at its lower end gradually narrows into a passage, the **canalis reuniens,** which connects the saccule with the ductus cochlearis. Its upper end bulges backward forming the **sinus utricularis,** whose wall comes in contact with that of the utricle. The small canal, already mentioned as helping to form the ductus endolymphaticus, arises from the posterior wall of the saccule. The **ductus endolymphaticus** passes through the aquæductus vestibuli to end in a blind dilated extremity, the **saccus endolymphaticus,** lying between the layers of the dura mater below the opening of the aqueduct. Through the openings in the recessus **sphæricus** branches of the vestibular nerve enter and pass to the macula acustica sacculi on the anterior wall of the saccule. The **canalis reuniens** is the very small tube passing from the lower part of the saccule into the upper wall of the cochlear duct near the **cæcum vestibulare**, as its blind vestibular end is called.

The Membranous Semicircular Canals.—These tubes (**ductus semicirculares**) occupy about one third of the diameter of the osseous canals and correspond

to them in number, name and form. They are closely united along their convex margins with the bony tube (Fig. 1270), whilst their opposite wall lies free in the perilymphatic space, being attached only by irregular vascular connective tissue bundles, **ligamenta labyrinthi canaliculorum,** which stretch across this space. Like the bony canals, each of the membranous tubes possesses an **ampulla,** which in the latter is relatively much larger than in the former, being about three times the size of the rest of the tube. The part of the ampulla corresponding to the convexity of the semicircular canal is grooved on the outer surface at the entrance of the ampullary nerves. On the corresponding internal surface is a projection, the **septum transversum,** which partially divides this space into two parts and is surmounted by the **crista acustica,** which contains the endings of the vestibular nerves. The crescent-shaped thickening beyond each end of the crista is called the **planum semilunatum.**

FIG. 1270.



Transverse section of superior semicircular canal, showing relations of membranous to bony tube. × 35.

Structure of the Utricle, Saccule and Semicircular Canals.—The **vestibule** and the **bony semicircular canals** are lined by a very thin periosteum composed of a felt-work of resistant fibrous tissue, containing pigmented connective tissue cells. Endothelium everywhere lines the perilymphatic space between the membranous and osseous canals, covering the free inner surface of the periosteum, the fibrous trabeculæ, and the outer or perilymphatic surface of this part of the membranous labyrinth.

The walls of the **utricle, saccule** and **membranous semicircular canals** are made up of (*a*) an outer fibrous *connective tissue lamella* and (*b*) an inner *epithelial lining*, the latter consisting throughout the greater part of its extent of a single layer of thin flattened polyhedral cells. Beneath the epithelium, especially in the region of the maculæ, is (*c*) a thin, almost homogeneous *hyaline membrane*, with few cells. This middle layer presents in places on its inner surface small papillary elevations covered by epithelium. On the concave side of each of the semicircular canals is a strip, the *raphe*, of thickened epithelium in which the cells become low cylindrical in type. In the plana semilunata they are cylindrical in type. Over the regions receiving the nerve-fibres, the maculæ acusticæ and the cristæ acusticæ, the epithelium undergoes a marked alteration, changing from the indifferent covering cells into the highly specialized neuroepithelium.

The **maculæ acusticæ** are about 3 mm. long by 2 mm. broad, the macula of the saccule being a little narrower (1.5–1.6 mm.) than that of the utricle (2 mm.). At the margin of these areas the cells are at first cuboidal, next low columnar, and then abruptly increase in length, until they measure from .030–.035 mm., in contrast with their usual height of from .003–.004 mm. The acoustic area includes two kinds of elements, the sustentacular or fibre-cells and the hair-cells. The *sustentacular cells* are long, rather narrow, irregularly cylindrical elements and extend the entire thickness of the epithelial layer, resting upon a well-developed basement-membrane by their expanded or divided basal processes. At a variable distance from the base, they present a swelling enclosing an oval nucleus and terminate at the surface in a cuticular zone. The cylindrical *hair-cells* are broader but shorter than the sustentacular cells, and reach from the free surface only as far as the middle of the epithelial layer, where each cell terminates usually in a

rounded or somewhat swollen end containing a spherical nucleus. The central end, next to the free surface, exhibits a differentiation into a cuticular zone, similar to that covering the inner ends of the sustentacular elements. From the free border of each hair-cell, a stiff robust hair (.020–.025 mm. long) projects into the endolymph. This conical process, however, is resolvable into a number of agglutinated finer hairs or rods.

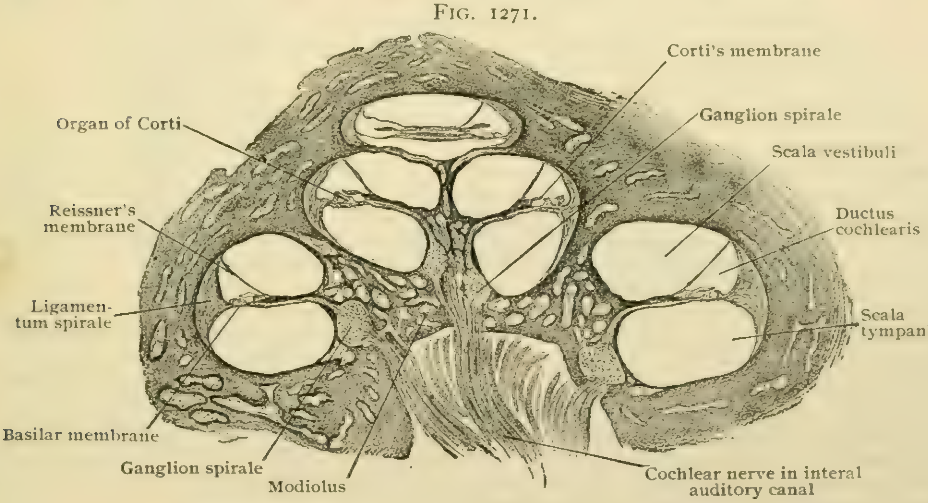
The free surface of the neuroepithelium within the saccule and the utricle is covered by a remarkable structure, the so-called **otolith membrane**. This consists of a gelatinous membrane in which are embedded numberless small crystalline bodies, the *otoliths* or *ear-stones*. Between it and the cuticular zone is a space, about .020 mm. in width and filled with endolymph, through which the hairs project to the otolith membrane. The otoliths (**otoconia**) are minute crystals, usually hexagonal in form, with slightly rounded angles, and from .009–.011 mm. in length. They are composed of calcium carbonate with an organic basis.

On reaching the macula the nerve-fibres form a subepithelial plexus, from which fine bundles of fibres pass toward the free surface. The fibres usually lose their medullary substance in passing through the basement membrane and enter the epithelium as naked axis-cylinders. Passing between the sustentacular cells to about the middle of the epithelium, they break up into fine fibrillæ, which embrace the deeper ends of the hair-cells and give off fine threads that pass as free axis-cylinders between the cells to higher levels.

The **crista acustica** and the **planum semilunatum** are covered with neuroepithelium similar to that of the maculæ. The hairs of the hair-cells, however, are longer and converge to and are embedded within a peculiar dome-like structure, known as the **cupola**, which probably does not exist during life, but is an artefact formed by coagulation of the fluid in which the ends of the hairs are bathed. Otoliths probably do not exist in the cristæ acusticæ.

The Cochlear Duct.—The **membranous cochlea** (**ductus cochlearis**) lies within the bony cochlea, and like it includes from two and one-half to two and three-quarter turns, named respectively the *basal*, *middle* and *apical*, the latter being

FIG. 1271.



Section of human cochlea passing through axis of modiolus. × 12.

three-fourths of a turn at the apex of the cochlea. The tapering tube of the bony cochlea, winding spirally around the modiolus, is subdivided into three compartments by the osseous spiral lamina and two membranes, namely, the membranous spiral lamina and Reissner's membrane. The **membranous spiral lamina** (**lamina basilaris**) or **basilar membrane** extends from the free border of the lamina spiralis ossea to the outer wall of the cochlea, where it is connected to an inward bulging of the periosteum and subperiosteal tissue, called the **spiral ligament.** The lower of the two tubes thus formed is the scala tympani and communicates, in the macerated skull, with the tympanum through the round window. The upper tube is subdivided into two compartments by an exceedingly delicate partition, known as **Reissner's membrane** (**membrana vestibularis**) which extends from the upper surface of the osseous lamina near its outer end, obliquely upward and outward, to the external wall of the cochlea. The compartment above this membrane is the

scala vestibuli and communicates with the perilymphatic space of the vestibule. The scalæ tympani and vestibuli communicate only at the apex of the cochlea through the helicotrema. They contain perilymph and are brought into relation with the subarachnoid space through the aquæductus cochleæ. They are lined by a delicate fibrous periosteum, usually covered on the surface which is in contact with the enclosed perilymph, by a single layer of endothelial plates. In some localities, however, as on the tympanic surface of the basilar membrane, the lining cells retain their primitive mesoblastic character and never become fully differentiated into endothelium.

The third compartment, the **ductus cochlearis,** is triangular on cross-section (Fig. 1271), except at its ends, and bounded by Reissner's membrane above, by the basilar membrane and a part of the osseous spiral lamina below, and by the outer wall of the bony cochlea externally. Save for the narrow channel, the canalis reuniens, by which it communicates with the saccule, the cochlear duct is a closed tube and contains endolymph. It begins below as a blind extremity, the **cæcum vestibulare,** lodged within the recessus cochlearis of the vestibule and, after making two and three-quarter turns through the cochlea, ends above at the cupola of the cochlea in a second blind extremity, the **cæcum cupulare,** or **lagena,** which is attached to the cupola and forms a part of the boundary of the helicotrema.

Architecture and Structure of the Cochlear Duct.—Reissner's membrane (**membrana vestibularis**), the delicate partition separating the cochlear duct from the scala vestibuli, begins on the upper surface of the lamina spiralis, about .2 mm. medial to the free edge of the bony shelf, and extends at an angle of from 40–45° with the lamina spiralis ossea to the outer wall of the cochlea, where it is attached to the periosteum. Notwithstanding its excessive thinness (.003 mm.), it consists of three layers: (*a*) a very delicate middle *stratum of connective tissue*, (*b*) the *endothelium* covering the vestibular side, and (*c*) the *epithelium* derived from the cochlear duct, and contains sparingly distributed capillary blood-vessels.

The **outer wall** of the cochlear duct (Fig. 1272) is bounded by a part of a thickened crescentic cushion of connective tissue, whose convex surface is closely united with the bony wall and whose generally concave surface looks toward the cochlear duct. This structure, the **ligamentum spirale,** extends slightly above the attachment of Reissner's membrane and to a greater distance below the attachment of the basilar membrane, thus forming part of the outer walls of the scalæ vestibuli and tympani. At its junction with the basilar membrane it presents a marked projection, the **crista basilaris,** whilst a very slight elevation marks the point of attachment of the membrane of Reissner. The part of this ligament lying between these projections corresponds to the outer wall of the cochlear duct. Its concave free inner surface is broken by a third elevation, the **prominentia spiralis,** or *accessory spiral ligament*, distinguished usually by the presence of one large (*vas prominens*) or several small blood-vessels. The lower and smaller of these two divisions of the outer wall is called the **sulcus spiralis externus** and is lined by cuboidal epithelium, whilst the larger upper division is occupied by a peculiar vascular structure, the **stria vascularis,** which contains capillary blood-vessels within an epithelial structure. Its surface is covered with pigmented irregular polygonal epithelial cells, and its deeper strata consist of cells which, especially in the superficial layers, resemble the surface epithelium, but in the deeper layers assume more and more the character of connective tissue. Over the prominentia spiralis the cells become flat and polyhedral.

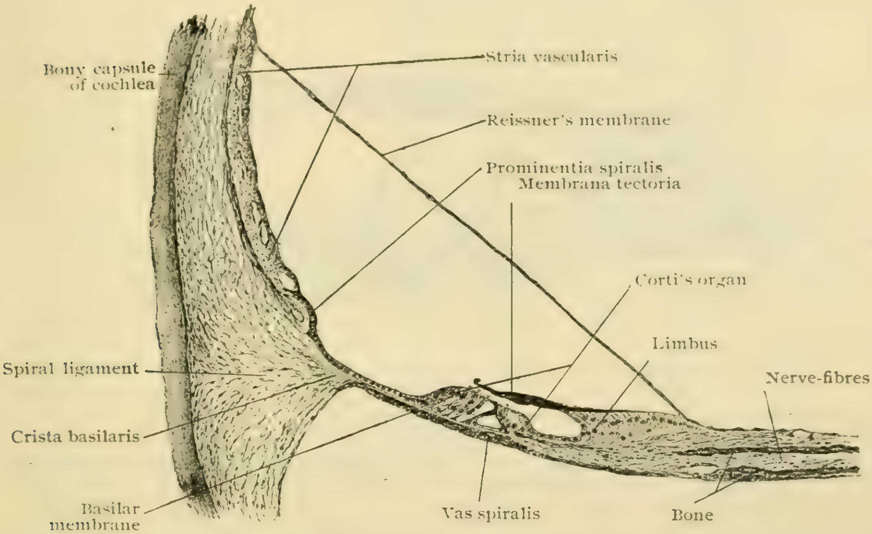
The **ligamentum spirale** is composed of a peculiar connective tissue, rich in cells and blood-vessels. Its thin outer layer forms the periosteum and is denser than the adjacent loose connective tissue. The latter is broadest opposite the scala tympani, where its fibres converge towards the crista basilaris. Opposite the outer wall of the cochlear duct it again becomes more compact and is rich in cells and blood-vessels. An internal layer extending from near the prominentia spiralis to the basilar membrane consists of a hyaline, noncellular tissue. Some authors claim to have found smooth muscle-fibres in the ligamentum spirale.

The **tympanic wall** or **floor** of the cochlear duct (Fig. 1272) comprises the *basilar membrane*, extending from the basilar crest to the outer end of the bony spiral lamina, and the *limbus laminæ spiralis*, which includes this wall from the attachment of Reissner's membrane to the end of the bony lamina. The **limbus** (**crista spiralis**) is a thick mass of connective tissue upon the upper surface of the outer end of the osseous lamina spiralis. Its outer extremity is deeply grooved to form a gutter, the **sulcus spiralis internus,** the projections of the limbus above and below the sulcus forming respectively its **superior** (vestibular) and **inferior** (tympanic) **labia.** The upper surface of the limbus is marked by clefts and furrows which are most conspicuous near the outer margin of the upper lip (**labium vestibulare**), where the irregular projections between

the furrows form the so-called **auditory teeth,** because of their fancied resemblance to incisor teeth. The **lower lip** (**labium tympanicum**) is continuous externally with the basilar membrane and is perforated near its outer end by some 4000 apertures (**foramina nervosa**), transmitting minute branches of the cochlear nerve. The epithelium covering the elevated portions of the limbus, including the auditory teeth, is of the flat polyhedral variety, the intervening furrows and clefts being lined by columnar cells. The epithelium of the sulcus spiralis consists of a single layer of low cuboidal or flattened cells, continuous with the epithelium of the auditory teeth above and with the highly specialized elements of Corti's organ below.

The **basilar membrane** consists of a median (inner) and a lateral (outer) part. The former, known as the **zona arcuata,** is thin and supports the modified neuroepithelium constituting the organ of Corti; the outer part, named the **zona pectinata,** is the thicker division and lies external to the foot-plates of the outer rods of Corti. The basilar membrane is made up of three distinct layers, the *epithelium,* the *substantia propria* and the *tympanic lamella.* The *substantia propria* is formed of an almost homogeneous connective tissue with a few nuclei and fine fibres, which radiate toward the outer edge of the spiral lamina. The fibres of the zona arcuata are very fine and interwoven, appearing to be an extension of those of the lower lip of the limbus, whilst straight and more distinct fibres stretch from the outer rods of Corti to the spiral ligament and constitute the so-called **auditory strings.** According to the estimate of Retzius, there are 24,000

FIG. 1272.



Cross-section of ductus cochlearis from human cochlea. × 90. Drawn from preparation made by Dr. Ralph Butler.

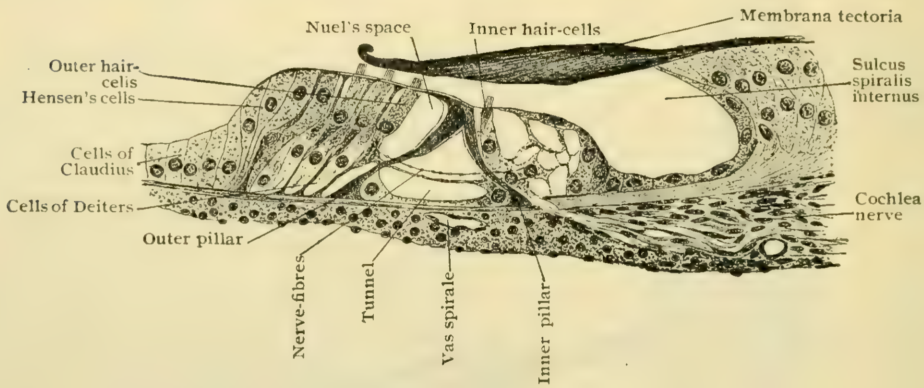
of these special fibres. Their length increases from the base toward the apex of the cochlea, in agreement with the corresponding increase in breadth of the basilar membrane. The *tympanic lamella* contains numbers of fusiform cells of immature character interspersed with fibres. In this location the differentiation of the mesoblastic cells lining the tympanic canal has never advanced to the production of typical endothelial plates, the free surface of the lamella being invested by the short fusiform cells alone. The inner zone of this layer contains capillaries which empty into one, or sometimes two, veins, frequently seen under the tunnel of Corti and known as the *vas spirale.* The *epithelium* covering the inner zone of the basilar membrane forms the organ of Corti, the highest example of specialization of neuro-epithelium.

The Organ of Corti.—The organ of Corti (**organon spirale**) consists in a general way of a series of epithelial arches formed by the interlocking of the upper ends of converging and greatly modified epithelial cells, the **pillars** or **rods of Corti,** upon the inner and outer sides of which rest groups of neuroepithelial elements—the **auditory** and the **sustentacular cells.** The triangular space included between the converging pillars of Corti above and the basilar membrane below constitutes the **tunnel of Corti,** which is, therefore, only an intercellular space of unusual size. It contains probably a soft semifluid intercellular substance serving to support the nerve-fibrils traversing the space (Fig. 1273). The **pillars** or **rods of Corti,** examined in detail, prove to be composed of two parts, the denser substance of the pillar proper, and a thin, imperfect protoplasmic envelope, which presents a triangular thickening at the base directed toward the cavity of the tunnel. Each pillar possesses a slender slightly sigmoid, longitudinally striated *body,* whose

upper end terminates in a triangular *head*, and whose lower extremity expands into the *foot* resting upon the basilar membrane. The inner pillar is shorter, more nearly vertical and less curved than the outer; its head exhibits a single or double concave articular facet for the reception of the corresponding convex surface of the head of the outer rod. The cuticular substance of both pillars adjoining the articular surfaces is distinguished by a circumscribed, seemingly homogeneous oval area of different nature. The upper straight border of the head of each pillar is prolonged outwardly into a thin process or *head-plate*, that of the inner lying uppermost and covering over the head and inner part of the plate of the outer pillar. The head-plate of the latter is longer and projects beyond the termination of the plate of the inner rod as the *phalangeal process*, which unites with the adjacent phalanges of the cells of Deiters to form the *membrana reticularis*. The inner pillars of Corti are more numerous, but narrower than the outer elements, from which arrangement it follows that the broader outer rods articulate with two and sometimes three of the inner pillars, the number of the latter in man being estimated by Retzius at 5600, as against 3850 of the outer rods.

Immediately medial to the arch of Corti, resting upon the inner rods, a single row of specialized epithelial elements extends as the **inner auditory** or **hair-cells**. These elements, little more than half the thickness of the epithelial layer in length, possess a columnar body containing an oval nucleus. The outer somewhat constricted end of each hair-cell is limited by a

FIG. 1273.



Section showing details of Corti's organ from human cochlea; owing to slight obliquity of section, width is somewhat exaggerated. × 375. Drawn from preparation made by Dr. Ralph Butler.

sharply defined cuticular zone, from the free surface of which project, in man, some twenty-five rods or hairs. The inner hair-cells are less numerous (according to Retzius about 3500), as well as shorter and broader, than the corresponding outer elements. Their relation to the inner rods of Corti is such, that to every three rods two hair-cells are applied. The **inner sustentacular cells** extend throughout the thickness of the epithelial layer and exhibit a slightly imbricated arrangement as they pass over the sides of Corti's organ to become continuous with the lower cells of the sulcus spiralis.

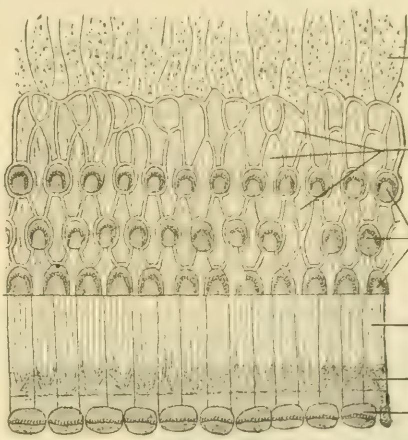
The cells covering the basilar membrane from the outer pillar to the basilar crest comprise three groups: (*a*) those composing the outer part of Corti's organ, including the *outer hair-cells* and *cells of Deiters*; (*b*) the *outer supporting cells*, or *cells of Hensen*; (*c*) and the low cuboidal elements, the *cells of Claudius*, investing the outermost part of the basilar membrane.

The **outer auditory** or **hair-cells** are about five times more numerous (approximately 18,000 according to Waldeyer) than the corresponding inner elements, and in man and apes are disposed in three or four rows. They alternate with the peculiar end-plates or "phalanges" of Deiters' cells, which separate the ends of the hair-cells and join to form a cuticular mesh-work, the *membrana reticularis*, through the openings of which the hair-cells reach the free surface. The inner row of these cells lies directly upon the outer rods of Corti, so placed that each cell, as a rule, rests upon two rods. The cells of the second row, however, are so disposed that each cell lies opposite a single rod, whilst the third layer repeats the arrangement of the first. In consequence of this grouping, these elements, in conjunction with the "phalanges," appear in surface views like a checker-board mosaic, in which the oval free ends of the auditory cells are included between the peculiar compressed and indented octagonal areas of the end-plates of Deiters' cells

(Fig. 1274). The outer hair-cells are cylindrical in their general form, terminating about the middle of the epithelial layer in slightly expanded rounded ends, near which the spherical nuclei are situated. The outer sharply defined ends of the cells are distinguished by a cuticular border supporting about twenty-five rigid auditory rods or hairs which project beyond the level of the membrana reticularis. The deeper end of each outer hair-cell contains a dense yellowish enclosure, known as the *body of Retzius*, which is triangular when seen in profile. The bodies are absent in the inner hair-cells.

The **cells of Deiters** have much in common with the rods of Corti, like these being specialized sustentacular epithelial cells which extend the entire thickness of the epithelial stratum to terminate in the peculiar end-plates or phalanges. It follows, that whilst the free surface of Corti's organ is composed of both auditory and sustentacular cells, the elements resting upon the basilar membrane are of one kind alone—the cells of Deiters. The bodies of the latter consist of two parts, the elongated cylindrical *chief portion* of the cell, containing the spherical nucleus and resting upon the basilar membrane, and the greatly attenuated pyramidal *phalangeal process*. A system of communicating intercellular clefts, the **spaces of Nuel**, lie between the auditory and supporting cells; like the tunnel of Corti, these spaces are occupied by a semifluid intercellular substance. The cells of Deiters are arranged, as a rule, in three rows, although in places within the upper turns four or even five alternating rows are sometimes found. Each cell contains a fine filament, the *fibre of Retzius*, which begins near the middle of the base with a conical expansion, and extends through the cell-body to the apex of the phalangeal process, where, according to Spee, it splits into seven or more fine end-fibrils, that extend into the cuticular superficial layer under and about the phalanges.

FIG. 1274.



Corti's organ viewed from above, showing mosaic formed by pillars and Deiters' cells; outer ends of auditory cells occupy meshes of cuticular net-work. (*Retzius*).

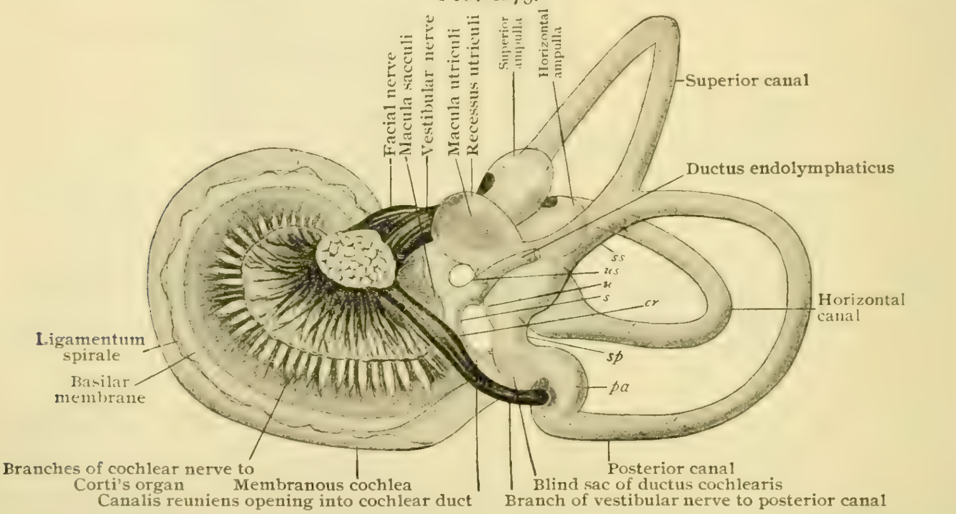
The **membrana tectoria** or **Corti's membrane** stretches laterally from the upper lip of the limbus, above the sulcus spiralis and Corti's organ, as far as the last row of outer hair-cells. The membrane is a cuticular production, formed originally by the cells covering the region of the auditory teeth and the spiral sulcus. Medially it rests upon the epithelial cells, but farther outward it becomes separated from the free edge of the auditory teeth and assumes its conspicuous position over the organ of Corti. The membrane seems to be composed of fine resistant fibres, held together by an interfibrillar substance. During life the membrane is probably soft and gelatinous, and much less rigid than its appearance indicates after the effect of reagents. The lower surface of the free portion of the membrane, opposite the inner hair-cells, is modelled by a shallow furrow, which indicates the position of a spirally arranged band known as the *stripe of Hensen*. Like the basilar membrane, the membrana tectoria increases in width from the base towards the apex of the cochlea.

The **outer sustentacular cells** or **cells of Hensen** form an outer zone immediately external to the last Deiters' cells. These elements resemble the inner sustentacular cells, but differ somewhat in form and arrangement. In consequence of their oblique position, the bodies are not only greatly elongated, but also imbricated. They do not contain the fibres of Retzius. The **cells of Claudius** are the direct continuations of Hensen's cells, and laterally pass uninterruptedly into the low columnar elements covering the remaining part of the basilar membrane. They consist of a simple row of cuboidal cells possessing clear, faintly granular protoplasm and spherical nuclei.

The Nerves of the Cochlea.—The branches of the cochlear division of the auditory nerve enter the base of the cochlea through the *tractus spiralis foraminosus* (page 1514), those destined for the apical turn traversing the central canal of the modiolus. From the modiolus a series of stout lateral branches diverge at quite regular intervals through canals which communicate with the peripheral spiral canal within the base of the bony spiral lamina. Within the peripheral canal the nerve-fibres join numerous aggregations of bipolar nerve-cells, which continue along the

spiral canal and collectively constitute the **ganglion spirale.** From these cells numerous dendrites are given off, which pass along the canals within the spiral lamina towards its margin, the twigs meanwhile subdividing to form an extensive plexus contained within corresponding channels in the bone. At the edge of the spiral lamina bundles of fine fibres are given off, which escape at the foramina nervosa of the labium tympanicum and enter the epithelial layer close to the inner rod of Corti. During or before their passage through the foramina, the nerve-fibres lose their medullary substance and proceed to their destination as fine naked axis-cylinders. The radiating bundles pass within the epithelium to the mesial side of the base of the inner pillar ; here they divide into two sets of fibrillæ, one, the *mesial spiral fasciculus*, going to the inner hair-cells and the other, the *lateral spiral fasciculus*, passing between the inner pillars to reach the tunnel of Corti. Within this space fibrillæ are given off which, after crossing the tunnel, escape between the outer rods into the epithelium lying on the lateral side of the arch. The further course of the fibrillæ seems to be such that some extend between the outer pillar of Corti and the first rows of hair-cells, whilst succeeding groups of fibrillæ course between the rows of Deiters'

FIG. 1275.



Membranous labyrinth of five months fœtus, postero-mesial aspect ; *u*, utricle ; *ss*, *sp*, superior and posterior utricular sinus ; *s*, saccule ; *us*, utriculo-saccular canal ; *cr*, canalis reuniens ; *pa*, posterior ampulla. × 6. (*Retzius*).

cells to reach the remaining hair-cells. The relation between the nerve-fibrils and the auditory cells is in all cases probably close contact and not actual junction with the percipient elements. The paths by which the impulses collected from the auditory cells are conveyed to the cochlear nucleus, and thence to the higher centres, are described in connection with the Auditory Nerve (page 1258).

Blood-Vessels of the Membranous Labyrinth.—The *arteries* supplying the internal ear arise from the internal auditory artery, supplemented to a limited extent by branches from the stylo-mastoid. The auditory artery, a branch of the basilar, after entering the internal auditory meatus divides, according to Siebenmann, into three branches :—(1) the *anterior vestibular*, (2) the *cochlear proper*, and (3) the *vestibulo-cochlear artery*.

1. The **vestibular artery** accompanies the utriculo-ampullary nerve and supplies the upper part of the vestibule, including the posterior part of the utricle with its macula, the saccule and the cristæ of the upper and outer ampullæ of the corresponding semicircular canals.

2. The **cochlear artery** pursues a spiral course. It gives off three branches, two of which are distributed to the lower turn of the cochlea, whilst the third supplies the middle and apical turns.

3. The **vestibulo-cochlear artery** arises either from the cochlear artery or independently and divides, within the spiral lamina, into a cochlear and a vestibular

branch. The *cochlear branch* is distributed to the lower turn of the cochlea and anastomoses with the cochlear artery proper. The *vestibular branch* is distributed to the lower part of the vestibule, including the lower part of the saccule and utricle, to the crus commune and part of the semicircular canals, and to the lower end of the cochlea. According to Siebenmann, the macula of the saccule receives its arterial supply from a blood-vessel which usually arises from the common stem of the vestibulo-cochlear artery, or, more rarely, runs independently through the whole internal meatus. A similar origin applies to the artery supplying the nerve of the posterior ampulla. In the base of the spiral lamina the arteries are connected by capillary loops especially in the lower turn of the cochlea. As mentioned above, one or more spiral vessels are often seen under the tunnel of Corti within the tympanic covering of the basilar membrane. The region of the stria vascularis and prominentia spiralis are especially well supplied with blood-vessels. Those seen in the scala tympani are principally veins, while a larger number of arteries are found in the scala vestibuli. The blood-supply of the lower turn of the cochlea is much more generous than that of the others.

The *veins* by which the blood escapes from the cochlea include: (1) the vein of the vestibular aqueduct, which empties into the superior petrosal sinus; (2) the vein of the cochlear aqueduct, which empties into the internal jugular and (3) the venous plexus of the inner auditory canal, which empties either into the transverse or inferior petrosal sinus. The first of these channels collects the blood from the semicircular canals; the second from the whole cochlear canal through the anterior, posterior and middle spiral veins and from most of the vestibule through the anterior and posterior vestibular veins. The veins of the internal auditory canal form collaterals to the other veins of the labyrinth and receive the large central cochlear vein (Siebenmann), which leaves the cochlea near the border of the central foramen of the modiolus, as well as tributaries corresponding to the branches of the acoustic nerve.

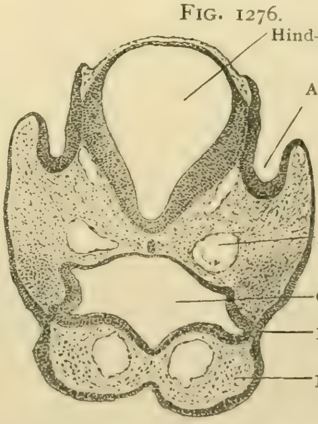
THE DEVELOPMENT OF THE EAR.

The development of the ear includes the formation of two morphologically distinct divisions, the *membranous labyrinth*, the essential auditory structure, and the *accessory parts*, comprising the middle ear, with its ossicles and associated cavities, and the external auditory canal and the auricle. The developmental history of the organ of hearing proper in its early stages is largely an account of the growth and differentiation of the ectoblastic **otic vesicle**, since from this is produced the important membranous tube, the enveloping fibrous and osseous structures being comparatively late contributions from the mesoblast.

Development of the Labyrinth.—The internal ear appears as a thickening and soon after depression of the ectoblast within a small area on either side of the cephalic end of the neural tube, at a level corresponding to about the middle of the hind-brain (Fig. 1276).

This depression, the **auditory pit**, is widely open for a considerable time and distinguished by the greater thickness of its depressed wall, which contrasts strongly with the adjacent ectoblast. After a time the lips of the pit approximate until, by their final union, the cup-like depression is converted into a closed sac, the **otic vesicle.**

Fig. 1276.



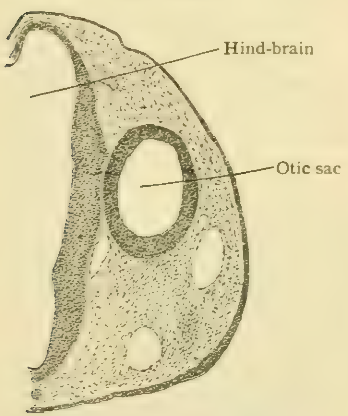
Frontal section of early rabbit embryo, showing otic pits. × 40.

This sac, after severing all connection with the ectoblast, gradually recedes from the surface in consequence of the growth of the intervening mesoblastic layer; it next loses its spheroidal form and becomes somewhat pear-shaped, with the smaller end directed dorsally. The smaller end rapidly elongates into a club-shaped diverticulum, the **recessus endolymphaticus,** which later becomes the ductus and the saccus endolymphaticus. The remainder of the otic sac soon exhibits a subdivision into a larger dilatation, the *vestibular pouch*, and a smaller ventral one, the *cochlear pouch* (Fig. 1279).

The **semicircular canals** differentiate from three folds which grow from the vestibular pouch opposite the attachment of the ductus endolymphaticus. The central parts of the two walls of each fold unite and undergo absorption, while the peripheral part of each fold remains open, thus forming a semicircular tube, one end of which becomes enlarged to form the ampulla. The superior vertical canal appears first, and the horizontal or external last. The growth of the epithelial diverticula is later accompanied by a condensation of the surrounding mesoblast, which differentiates into an external layer, the future cartilaginous and later bony capsule ; a layer internal to this becomes the perichondrium and later periosteum. A second mesoblastic layer is formed from the cells immediately surrounding the otic vesicle, whilst the space between these fibrous layers is filled by a semi-gelatinous substance which later gives place to the perilymph occupying the perilymphatic space. Within the ampullæ, which early develop, the epithelial lining undergoes specialization, accompanied by thickening of the mesoblastic wall within circumscribed areas, to form the cristæ acusticæ.

Coincidently with the development of the semicircular canals, a diverticulum, the **cochlear canal**, appears at the lower anterior end of the membranous sac. This tube, oval in section, grows forward, downward, and inward, and represents the future cochlear duct. After attaining considerable length, further elongation is accompanied by coiling and the assumption of the permanent disposition of the tube. The epithelium of the cochlear tube early exhibits a distinction, the cells of the upper surface of the somewhat flattened canal becoming attenuated, whilst those on the lower wall undergo thickening and further differentiation. The flattened cells form the epithelial covering of Reissner's membrane and of the outer wall, and the taller elements are converted into the complicated structures of the tympanic wall of the ductus cochlearis, , including the crista, the sulcus, and the organ of Corti.

FIG. 1277.



Part of frontal section of head of rabbit embryo ; otic sac is separated from ectoblast and beginning to elongate. × 40.

The development of these structures includes the differentiation of two epithelial ridges ; from the inner and larger of these is derived the lining of the sulcus spiralis and the overhanging membrana tectoria. The outer ridge is made up of six rows of cells, the inner row becoming the inner hair-cells, the outer three rows becoming the outer hair-cells, whilst the two rows between these two groups form the rods of Corti. The crista appears between the sulcal cells and the cochlear axis as a thickening of the spiral lamina.

The cochlear outgrowth of the primary otic vesicle forms the **membranous cochlea**, or scala media, alone, the walls of the adjacent divisions, the **scala vestibuli** and **scala tympani**, resulting from the changes within the surrounding mesoblast. The latter differentiates into two zones, an outer, which becomes the cartilaginous, and finally osseous, capsule, and an inner, lying immediately around the membranous canal, which for a time constitutes a stratum of delicate connective tissue between the denser capsule and the ectoblastic canal. Within this layer clefts appear, which gradually extend until two large spaces bound the membranous cochlea above and below.

These spaces, the scala vestibuli and the scala tympani, are separated for a time from the scala media by a robust septum consisting of a mesoblastic layer of considerable thickness and the wall of the ectoblastic tube. With the further increase in the dimensions of the lymph-spaces, the partitions separating them from the cochlear duct are correspondingly reduced, until, finally, the once broad layers are represented by frail and attenuated structures, the **membrane of Reissner** and the **basilar membrane**, which consequently include an ectoblastic stratum, the epithelial layer, strengthened by a mesoblastic lamina, represented by the substantia propria and its endothelioid covering.

The main sac of the otic vesicle from which the foregoing diverticula arise constitutes the **primitive membranous vestibule**, and later subdivides into the saccule and utricle. This separation begins as an annular constriction of the primitive vestibule, incompletely dividing the vesicle into two compartments. The still relatively large ductus endolymphaticus, the direct successor of the recessus endolymphaticus, unites with the narrow canal connecting these vesicles in such a manner that each space receives one of a pair of converging limbs, an arrangement foreshadowing the permanent relations of the parts.

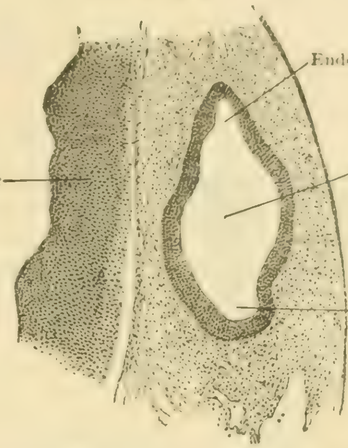
Even before the subdivision of the primitive vestibule is established, the vestibular end of the cochlear canal becomes constricted, so that communication between this tube and the future saccule is maintained by only a narrow passage, later the **canalis reuniens**. The development of the maculæ acusticæ of the saccule and utricle depends upon the specialization of

the epithelium within certain areas associated with the distribution of the auditory nerves. The nerve-fibres form their ultimate relations with the sensory areas by secondary growth into the epithelial structures.

Development of the Auditory Nerves.—The vestibular and cochlear nerves, according to Streeter[1], develop from a ganglion-mass first seen at the anterior edge of the otic vesicle. This consists of an upper and lower part from the dorsal and ventral portion of which peripheral nerve branches are developed, whilst a single stem connects it with the brain.

The nerves destined for the utricle and the superior and external ampullæ develop from the upper part of the ganglionic mass, while the nerves which supply the saccule and posterior ampulla develop from the lower part of this mass. The stem extending centrally from the ganglion toward the brain becomes the vestibular nerve.

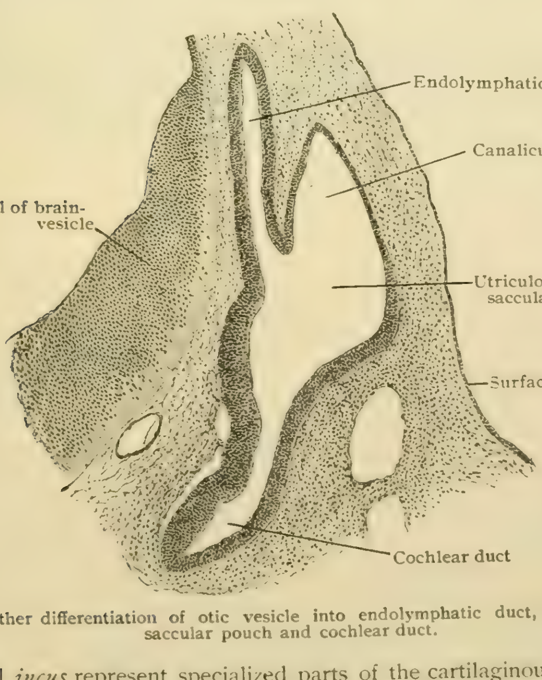
FIG. 1278.



Otic vesicle shows differentiation into three subdivisions, endolymphatic, vestibular and cochlear. × 40.

The **spiral ganglion** begins its development at the ventral border of the lower part of this mass, the cochlear nerve growing toward the brain while the peripheral division containing the ganglion extends into the membranous cochlea. From the foregoing sketch, it is evident that the membranous labyrinth is genetically the oldest part of the internal ear, and that it is, in fact, only the greatly modified and specialized closed otic vesicle surrounded by secondary mesoblastic tissues and spaces.

FIG. 1279.



Further differentiation of otic vesicle into endolymphatic duct, utriculo-saccular pouch and cochlear duct.

Development of the Middle Ear.—The tympanic cavity and the Eustachian tube are formed essentially by the backward prolongation and secondary expansion of the inner entoblastic portion of the first branchial furrow, the pharyngeal pouch. The dorsal part of the latter, in conjunction with the adjacent part of the primitive pharynx, gives rise to the secondary *tubo-tympanic space* (Fuchs); the posterior end of this becomes dilated to form the **tympanic cavity,** while the segment intervening between the tympanic diverticulum and the pharynx is converted into the **Eustachian tube.** The first and second branchial arches contribute the roof of the tympanic cavity.

The **ear ossicles** are developed in connection with the primitive skeleton of the visceral arches. The *malleus* and *incus* represent specialized parts of the cartilaginous rod of the first arch, the tensor tympani being developed from the muscular tissue of the same arch. The *stapes* is developed from the second arch. The mesoblast which surrounds the structures of the tympanic cavity during their development becomes spongy and finally degenerates toward the end of fœtal life.

[1] Amer. Jour. of Anatomy, Vol. VI., 1907.

The *air-cells* of the temporal bone, including those of the mastoid process, are formed later by a process of absorption.

The **tympanic membrane** results principally from changes which take place in the first branchial arch; it is originally thick and consists of a mesoblastic middle stratum, covered on its outer surface by the ectoblast and on its inner surface by the entoblast.

Development of the External Ear.—The median portion of the ectoblastic groove of the first branchial furrow becomes deepened to form the outer part of the **external auditory canal,**

FIG. 1280.

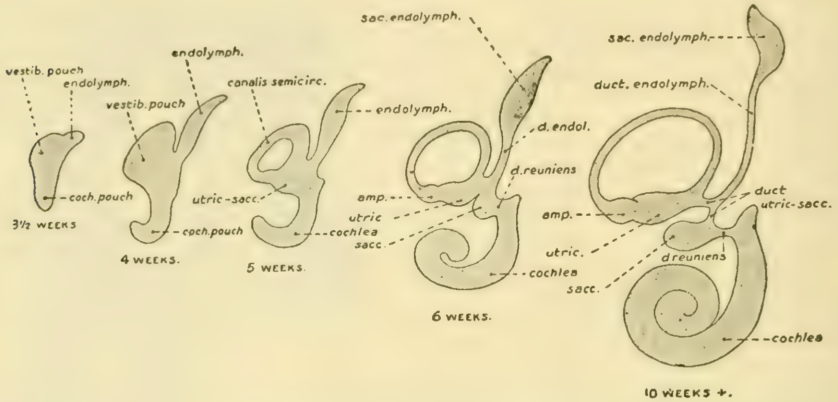


Diagram illustrating development of human membranous cochlea; primary otic vesicle subdivides into vestibular and cochlear pouches and endolymphatic appendage; cochlear pouch becomes ductus cochlearis; from vestibular pouch are derived utricle, saccule and semicircular canals; whilst endolymphatic appendage gives rise to endolymphatic sac and duct. (*Streeter.*)

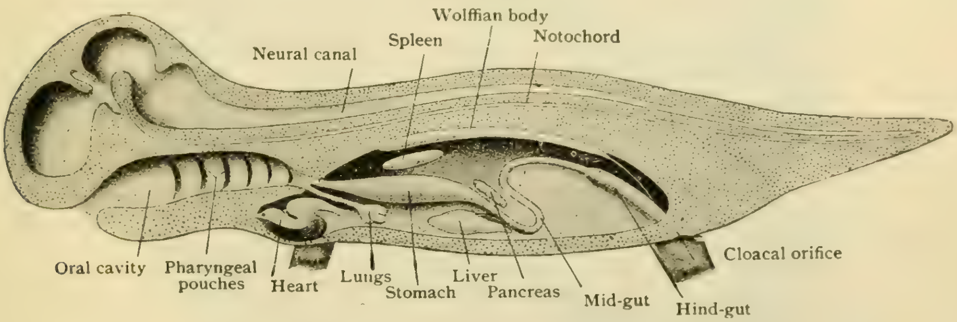
while the surrounding parts of the first and second arches develop into the **auricle.** About the fourth week of fœtal life, the thickened posterior margin of the first arch is broken up into three tubercles by two transverse furrows. Similarly on the adjoining margin of the second arch, a second vertical row of three tubercles is formed and, in addition, behind these a longitudinal groove appears marking off a posterior ridge. From these six tubercles and the ridge are differentiated the various parts of the auricle, the lowest nodule of the first arch becoming the ***tragus,*** the remaining ones with the ridge giving rise to the *helix*, whilst from the three tubercles of the second arch are developed, from above downward, the *antihelix*, the *antitragus* and the *lobule*.

THE GASTRO-PULMONARY SYSTEM.

GENERAL CONSIDERATIONS.

THE food-stuffs required to compensate the continual loss occasioned by the tissue-changes within the body are temporarily stored within the digestive tube. During this sojourn the food is subjected to the digestive processes whereby the substances suitable for the nutritive needs of the animal are separated by absorption from the superfluous materials which, sooner or later, are cast out as excreta. Closely associated with digestion, and in a sense complementary to it, is the respiratory function by which the supply of oxygen is assured. In the lowest vertebrates these two life-needs, food and oxygen, are obtained from the water in which the animal lives, this medium containing both nutritive materials and the air required for the performance of the respiratory interchange of gases (oxygen and carbon dioxide).

FIG. 1281.



Sagittal section of schematic vertebrate (*Modified from Fleischmann.*)

Since, therefore, in these animals both food and oxygen are secured from the same source, the water, the digestive and respiratory organs form parts of a single gastro-pulmonary apparatus. This close relation is seen in the lower vertebrates (fishes), in which the anterior segment of the digestive tube is connected on either side with a series of pouches and apertures, the *branchial clefts*, bordered by the vascular gill-fringes by means of which the blood-stream is brought into intimate relation with the air-containing water.

When the latter element is forsaken as a permanent habitat and the animal becomes terrestrial, a more highly specialized apparatus, suited for aërial respiration, becomes necessary. This need results in the development of the lungs. The latter, however, retain the intimate primary relation to the digestive tract, and are formed as direct ventral outgrowths from the gut-tube.

The vertebrate digestive tract early becomes differentiated into three divisions: *fore-gut*, *mid-gut*, and *hind-gut*. The first includes the mouth, pharynx, œsophagus, and stomach, and serves for the mechanical and chemical preparation of the food materials. The second comprises the longer or shorter, more or less convoluted small intestine, and forms the segment in which absorption of the nutritive materials chiefly takes place. The third embraces the large intestine, and contains the superfluous remains of the ingested materials which are discarded from the body at the

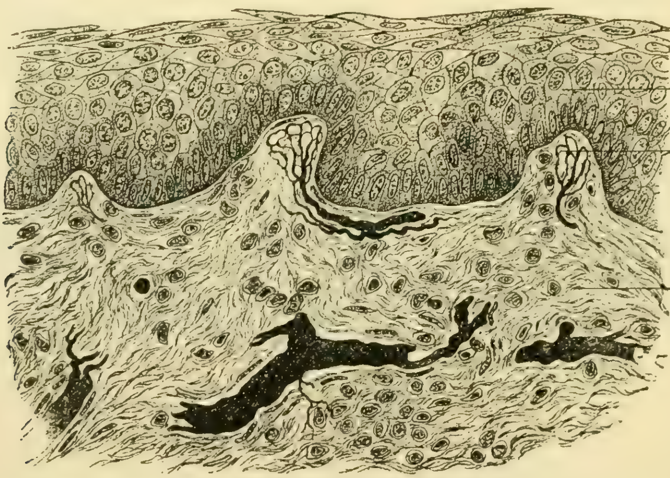
anal opening. Associated with the mid-gut are two important glands, the liver and the pancreas. Greater complexity in the character of the food and in the manner of securing it necessitates increased specialization in the first segment of the digestive tube ; hence the addition of accessory organs, as the lips, oral glands, tongue, and teeth, the latter often serving as prehensile as well as masticatory organs.

Reference to the early relations of the embryo to the vitelline sac (page 32) recalls the important fact that the greater part of the gut-tract is formed by the constriction and separation of a portion of the yolk-sac by the approximation and closure of two ventral folds, the splanchnopleura. Since the latter consists of two layers, the entoblast and the visceral lamina of the mesoblast, the tube resulting from the union of the splanchnopleuric folds possesses a lining directly derived from the inner germ-layer, supplemented externally by mesoblast. The latter contributes the connective tissue, muscular and vascular constituents of the digestive tube, while the epithelium and the associated glandular elements are the products of the entoblast.

MUCOUS MEMBRANES.

The apertures of the digestive, respiratory, and genito-urinary tracts mark locations at which the integument becomes continuous with the walls of cavities and passages communicating with the exterior. The linings of such spaces constitute

FIG. 1282.



Section of oral mucous membrane. × 350.

mucous membranes. The latter, however, not only form the free surface of the chief tracts, but also that of the ducts and tubes continued into the glands which are developed as outgrowths from the mucous membranes.

Temporarily in the higher types and permanently in such of the lower animals as possess a common cloacal space, all the mucous membranes of the body are continuous. After acquiring the definitive arrangement whereby the uro-genital tract becomes separated from the digestive tube, these membranes in man and mammals (except monotremata) form two great tracts, the *gastro-pulmonary* and the *genito-urinary.*

The free surfaces of the mucous membranes are kept continually moist by a viscid, somewhat tenacious secretion, the *mucus*, derived from the glands ; they are thus protected from the drying and irritating influences of the air, foreign substances, and secreted or excreted matters with which they are brought into contact.

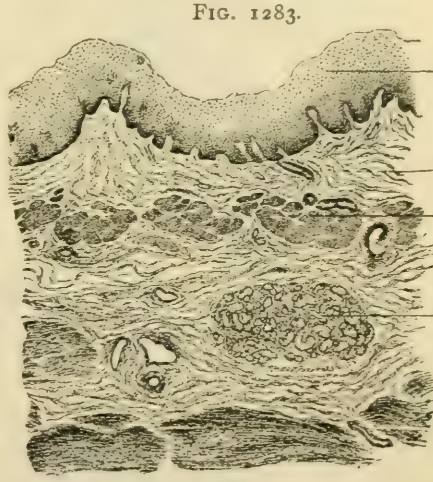
Structure.—Every mucous membrane comprises two distinct parts : the *epithelium*, which forms the immediate free surface and furnishes protection for the more delicate tissues beneath ; and the *tunica propria*, a connective-tissue layer which constitutes the stroma and gives place and support to the terminal branches of the

nerves and the blood-vessels and the beginnings of the lymph-radicles. Thus it will be seen that the general structure of a mucous membrane corresponds closely with that of the integument, the protecting epidermis of the latter being represented by the epithelium of the former, while both the corium and the tunica propria include the connective-tissue basis over which the epithelial layer stretches. A stratum of *submucous tissue*, corresponding with the subcutaneous layer in the skin, connects the mucous membrane with the surrounding structures.

The *epithelium* may be squamous or columnar, simple or stratified. Its character is usually determined by the conditions to which it is subjected; thus, where covering surfaces exposed to mechanical influences of foreign bodies, it is commonly stratified squamous, as in the upper part of the digestive tract. Where, on the other hand, the mucous membrane is concerned in facilitating absorption, as in the intestinal tube, the epithelium is simple columnar in type. In localities in which the existence of a current favors the function of an organ, either as a means of freeing the surface from secretion or particles of foreign matter, as in the respiratory tract, or of propulsion through a tube, as in the epididymis or the oviduct, the epithelium is of the ciliated columnar variety. Modifications of the epithelial cells, due to the presence of pigment or of secretion, distinguish certain mucous membranes, as those clothing the olfactory region and the large intestine respectively.

The *tunica propria* or *stroma* consists of interlacing bundles of fibro-elastic tissue which support spindle or stellate connective-tissue cells. The latter usually lie within the uncertain clefts between the stroma bundles, which may be regarded as lymph-spaces. In many localities the surface of the tunica propria is beset with numerous elevations or *papillæ*, over which the epithelium extends. Such irregularities, when slight, may not modify the free surface of the mucous membrane, since the epithelial layer completely fills the depressions between the elevations; when more pronounced, the papillæ or folds of the connective tissue produce the conspicuous modelling of the surface seen in the papillæ of the tongue or the rugæ of the vagina. The papillæ contain the terminal loops of the blood-vessels and the nerves supplying the mucous membrane. Where especially concerned in absorption, the mucous membranes often gain increase of surface by cylindrical elevations, or *villi*, as conspicuously seen in the small intestine. These projections, consisting of the stroma covered by epithelium, contain the absorbent vessels, or lacteals, in addition to the blood-capillaries.

FIG. 1283.



Section of mucous membrane of œsophagus. × 55.

A more or less well-defined line separates the epithelium from the subjacent tunica propria. This demarcation is the *basement membrane*, or *membrana propria*, a detail which has been variously interpreted. Usually the basement membrane appears as a mere line beneath the epithelium, and is then, probably, formed by the apposition of the basal processes of the epithelial cells. When surrounding glandular tissue it is better developed, presenting a distinct and much more robust structure. In these positions the basement membrane is probably a product of the tunica propria and occurs in two types, sometimes being homogeneous, at other times reticular (Flint[1]).

In many localities the deepest part of the mucous membrane, next the submucous tissue, is occupied by a narrow layer of involuntary muscle, the *muscularis mucosæ*. While not everywhere present, it is especially well developed in the intestinal tract from the gullet to the anus, and in places consists of two distinct layers,

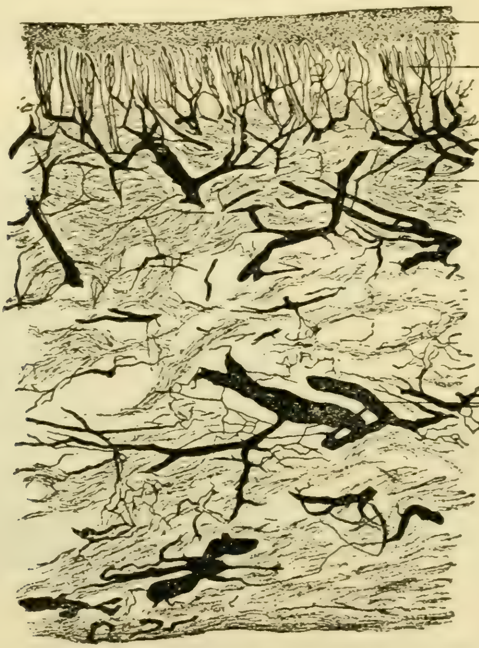
[1] American Journal of Anatomy, vol. ii., No. 1, 1902.

a circular and a longitudinal. The inner surface of the stratum is often broken by processes of muscular tissue which penetrate the tunica propria well towards the epithelium. The muscularis mucosæ belongs to the mucous membrane, and therefore must be distinguished from the muscular coat proper, which is frequently a conspicuous additional layer in the digestive tract.

Mucous membranes are attached to the surrounding structures by a *submucous layer* of areolar tissue. The latter varies in thickness and density, consequently the firmness of the union between the mucous and submucous strata differs greatly in various localities. Usually the attachment is loose, and readily permits changes in position and tension of the mucosa, which, in the relaxed condition, is often thrown into temporary folds or *rugæ*, as in the œsophagus and stomach. In other places the folds are permanent and not effaced by distention of the organ ; a conspicuous example of such arrangement is seen in the valvulæ conniventes of the small intestine, in which the submucous tissue forms the basis of the elevation.

The *blood-vessels* supplying mucous membranes reach the latter by way of the submucous tissue, in which the larger branches divide into the twigs which pass into

FIG. 1284.



Section of injected oral mucous membrane. × 60.

the mucosa. Within the deeper parts of the tunica propria the smaller arterial branches break up into the capillaries forming the subepithelial and papillary networks, the vascular loops being limited to the connective tissue stroma and never entering the epithelium. The venous stems usually follow the arteries in their general course. When glands are present, the capillaries surround the tubules or alveoli with rich net-works in close relation to the basement membrane.

The *lymphatics* within mucous membranes are seldom present as definite channels, since they begin as the uncertain interfascicular clefts between the bundles of stroma-tissue. Towards the deeper parts of the mucosa the lymph-paths become more definite, and exist as delicately walled varicose passages which converge towards the submucous tissue. Within the latter the lymph-vessels form net-works richly provided with valves and the accompanying dilatations.

The *nerves* distributed to mucous membranes include cerebral or spinal and sympathetic branches, the latter supplying especially the involuntary muscle of the

stroma and of the blood-vessels. Surfaces highly endowed with general and tactile sensibility are provided with a generous supply of twigs containing medullated fibres. As the latter pass towards their ultimate destination (for convenience assuming that all are peripherally directed) they lose their medullated character and, as naked axis-cylinders, form the *subepithelial plexuses*, from which delicate filaments pass into the papillæ, where they terminate either as free club-shaped or special sensory endings. It is probable that in places the nerves penetrate between the epithelial cells forming the layers next the basement epithelium and terminate in varicose free endings.

GLANDS.

Certain of the epithelial cells lining the mucous membranes of the body become modified to assume the rôle of secretion-forming organs or glands, the products of which are poured out upon the free surface and keep the latter moist. The latter purpose is secondary in the case of many important glands, as the parotid, pancreas,

FIG. 1285.

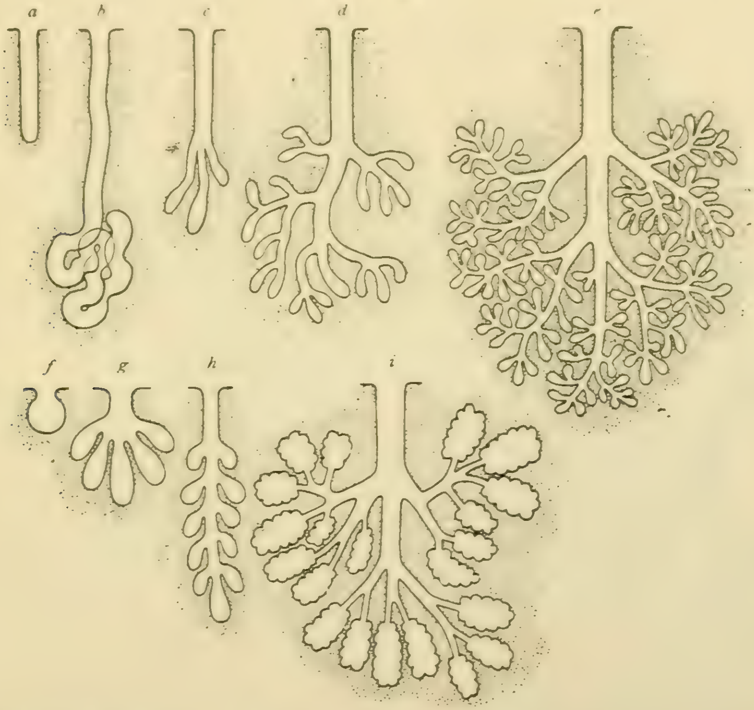


Diagram showing types of glands. *a-e*, tubular; *f-i*, alveolar or saccular. *a*, simple; *b*, coiled; *c-d*, increasingly complex compound tubular; *e*, tubo-alveolar; *f*, simple; *g-h-i*, progressively complex compound alveolar.

or liver, since these organs supply special secretions for particular ends. Aggregations of the secreting elements vary greatly in size, form, and arrangement, as well as in the character of their products.

The simplest type is the *unicellular gland* found in the lower forms: in principle this is represented in man and the higher animals by the goblet-cells seen in profusion in mucous membranes covered with columnar epithelium. The secretion poured out by these goblet-cells serves to protect and lubricate the surface of the mucous membranes in which they occur. The term "gland," however, usually implies a more highly developed organ composed of a collection of secreting epithelial elements.

Glands are classified according to their form into two chief groups, the *tubular* and the *alveolar*, each of which occurs as *simple* or *compound*. It should be emphasized that in many instances no sharp distinction between these conventional groups

exists, some important glands, as the salivary, being in fact a blending of the two types; such glands are, therefore, appropriately termed *tubo-alveolar*.

In the least complex type, the simple tubular, the gland consists of a cylindrical depression lined by epithelium directly continuous with that covering the adjacent surface of the mucous membrane, as an outgrowth of which the gland originally developed. In such simple gland the two fundamental parts, the *fundus* and the *duct*, are seen in their primary type. The fundus includes the deeper portion of the gland in which the epithelium has assumed the secretory function, the cells becoming larger and more spherical in form, while in structure the distinction between the spongioplasm and hyaloplasm is usually marked in consequence of the particles of secretion stored up within the meshes of the spongioplastic net-work, which is often sharply displayed. The duct connects the fundus with the free surface and carries off the products elaborated within the gland. It is lined with cells which take no part in secretion and hence retain for some distance the character of the adjacent surface epithelium. Dilatation of the fundus of the primitive type produces the simple alveolar or saccular gland; division of the fundus and part of the duct gives rise to the compound tubular variety; repeated cleavage and subdivision of the duct, with moderate expansion of the associated terminal tracts, lead to the production of the tubo-alveolar type.

Fig. 1286.

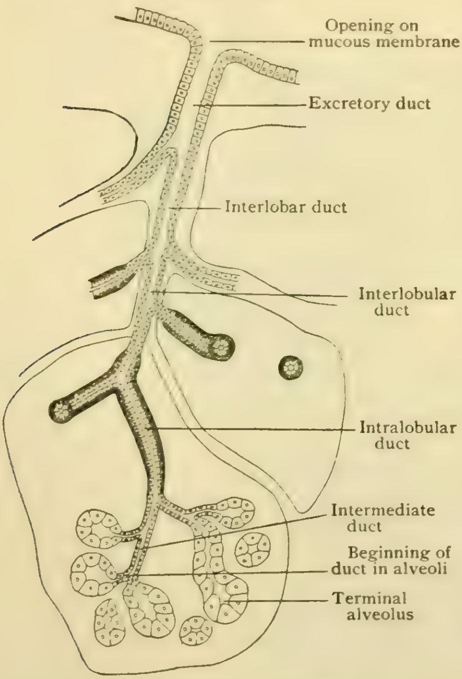


Diagram showing relations of various portions of duct-system in glands of tubo-alveolar type.

Simple tubular glands may be minute cylindrical depressions of practically uniform diameter, as the crypts of Lieberkühn in the intestine, or they may be somewhat wavy and slightly expanded at the fundus, as often seen in the gastric glands towards the cardiac end of the stomach. When the torsion becomes very pronounced, as in the sweat-glands, the *coiled* variety results.

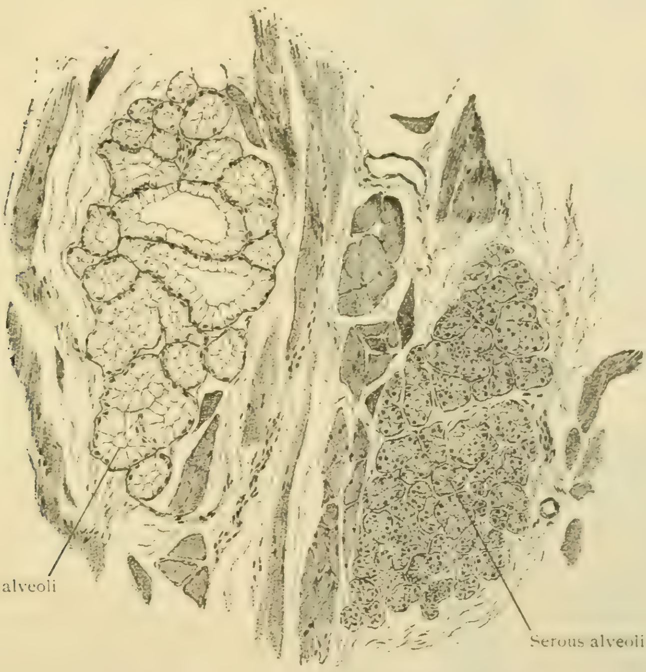
Compound tubular glands present all degrees of complexity, from a simple bifurcation of the fundus and adjacent part of the duct, as in the pyloric or uterine glands, to the elaborate duct-system ending in terminal divisions either of a tubular form, as in the kidney and testicle, or of a modified, somewhat dilated, alveolar form, the tubo-alveolar type, as in the salivary glands.

Tubo-alveolar glands, modified compound tubular, constitute a very important group, since they embrace many of the chief secretory organs of the body. They are made up by repetition of similar structural units, differences in the size of the organ depending upon the number of those associated to compose the gland. These units correspond to the groups of terminal compartments, or *alveoli*, connected with a single ultimate division of the duct-system. The alveoli or acini contain the secreting cells, and are limited externally by a basement membrane, often well developed, which supports the glandular epithelium and separates the latter from the blood- and lymph-vessels that surround the acinus.

The alveoli belonging to the same intermediate duct, held together by delicate connective tissue, constitute a pyramidal mass of glandular tissue, the *primary lobules*. The latter are assembled into larger groups, or *secondary lobules*, which in turn are united by interlobular connective tissue into the *lobes* composing the entire gland. The lobes are held together more or less firmly by the interlobar areolar tissue continuous with the general fibrous envelope, which forms a capsule for the entire organ and separates it from the surrounding structures.

The interlobar tissue and its interlobular continuations contain the blood-vessels, lymphatics, and nerves supplying the gland and, in addition, the major portion of the excretory ducts. In the larger glands the latter form an elaborate system of passages arranged after the general plan shown in the accompanying diagram (Fig. 1285). Traced from the terminal compartments, or alveoli, of the gland, the duct-system begins as a narrow canal, the *intermediate duct*, lined by low cuboidal or flattened cells directly continuous with the glandular epithelium of the alveoli. After a short course the tube increases in diameter and becomes the *intralobular duct*, which is often conspicuous on account of its tall and sometimes striated or rod-epithelium. The further path of the excretory tubules lies within the connective tissue separating the divisions of the glandular substance, and embraces the *interlobular* and the *interlobar ducts*, the latter joining to form a single main *excretory duct* which opens upon the free surface of the mucous membrane. The last-named passage is lined for some distance by cells resembling those covering the adjacent mucous membrane; where these are stratified squamous in type, this character is maintained for only a limited

FIG. 1287.



Section of posterior part of tongue, showing alveoli of serous and mucous types of glands. × 60.

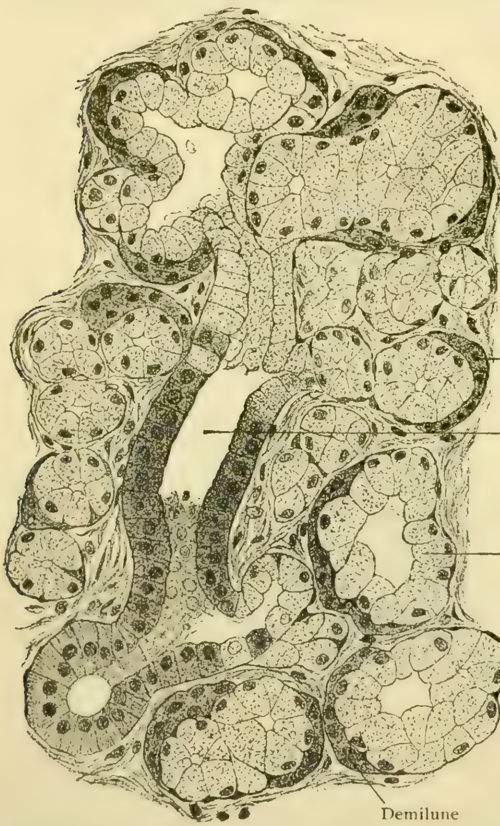
extent, before the interlobar ducts are reached gradually giving place to a simple, sometimes at first double, layer of columnar epithelium which extends as far as the intralobular tubules. The walls of the larger ducts consist of a fibro-elastic coat, lined by epithelium, and sometimes, in the case of the large glands, as the parotid, liver, pancreas, or testicle, are strengthened externally by a layer of involuntary muscle. In the case of the large ducts the latter is usually disposed as a transverse and longitudinal layer, to which, as in the hepatic duct (Hendrickson), a third oblique one may be added. Differential stains show the presence of a large amount of elastica.

The *glandular epithelium* lining the alveoli rests upon the limiting basement membrane as a single layer of irregularly spherical or polygonal secreting cells; these do not completely fill the alveolus, but leave an intercellular cleft into which the product of the cells is poured and in which the system of excretory ducts begins. Depending upon the peculiarities of the cells and the character of their secretion, glands are divided into *serous* and *mucous*.

The **serous glands** are distinguished by cells which are distinctly granular, generally pyramidal in form, with nuclei situated in the vicinity of the centre. The secretion elaborated by such glands is thin and watery. The general appearance of the cells depends upon the number and size of the granules stored within their cytoplasm, and changes markedly with the variations of functional activity of the gland. When a serous gland is in a condition of rest, the cells are loaded with secretion, and appear, therefore, larger and coarsely granular. After active secretion, on the contrary, the cells are exhausted and smaller and contain little of their product, often exhibiting differentiation into a clear outer zone, free from granules, and a darker inner zone, next the lumen, in which the granules still remain.

The **mucous glands** elaborate a clear, viscid, homogeneous secretion, which, when present in considerable quantity, as during rest, distends the cells, crowding the nuclei to the periphery against the basement membrane, and gives to the glandular epithelium a clear and transparent appearance in marked contrast to the granular character of the elements of a serous gland. During rest, when loaded and distended with mucoid secretion, the transparent cells possess well-defined outlines, and present a narrow peripheral zone containing the displaced nuclei and granular protoplasm. After prolonged activity the exhausted cells contain relatively little mucoid secretion, and hence the threads of spongioplasm are no longer widely separated, but lie closely ; in consequence of these changes the cells lose their former transparency and resemble the elements of serous glands, becoming smaller, darker, and more granular than the cells of the quiescent mucous gland.

FIG. 1288.



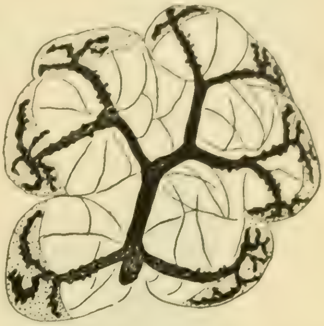
Section of human sublingual gland, showing serous cells arranged as demilunes. × 300.

The alveoli of mucous glands often contain small crescentic groups of small granular cells lying between the usual larger clear elements and the basement membrane ; these are the *crescents of Gianuzzi*, or *demilunes of Heidenhain*, the interpretation of which has caused much discussion. The older view regarded the crescents as groups of cells differing from the surrounding ones only in their stage of activity and not in their essential characters, all the cells within the alveolus being of the same nature. The opposite view, advanced by Ebner over a quarter of a century ago, has received support from more recent critical studies by Küchenmeister, Solger, Oppel, R. Krause, and others, who have shown that the cells composing the crescents differ from the mucus-containing elements, elaborate a special secretion, and are similar to, if not identical with, those filling the alveoli of serous glands. According to these observers, the crescents are groups of serous cells compressed and displaced by the predominating mucous elements, but not excluded from the lumen of the alveolus, as was

formerly thought to be the case, since extensions of the lumen pass between the mucous cells to reach the demilunes.

In addition to the main alveolar lumina, always narrow in serous and wider in mucous acini, the existence of intercellular passages, or *secretion-capillaries*, has been established for many glands, especially by the employment of the Golgi and other special methods. These clefts penetrate laterally between the glandular epithelium from the axial lumen towards the basement membrane, partially enclosing the secreting cells with a branching system of minute canals. Alveoli containing exclusively mucous cells do not possess these intercellular canaliculi, the axial lumen alone being present. In acini of the serous type the accessory channels are represented by minute branching passages which penetrate between the cells, but seldom reach the basement membrane. The most conspicuous of the secretion-capillaries occur in alveoli containing the demilunes, the product of the serous cells escaping into the main lumen by means of the lateral intercellular canals which pass between the mucous elements to reach the peripheral group of serous cells composing the crescent. The view that the secretion-capillaries normally extend into the cytoplasm of the glandular epithelium, and are, therefore, also intracellular, must be regarded as doubtful and still undecided, although supported by many able histologists.

FIG. 1289.



Section of several alveoli of submaxillary gland of dog, showing terminal ducts and secretion-capillaries passing to crescentic (stippled) groups of serous cells. × 500. (*Retzius.*)

Depending upon the distribution of the two varieties of alveoli, the tubo-alveolar glands may be divided into four groups (Ebner):

1. *Pure serous glands*, in which only serous alveoli occur, as the parotid.
2. *Mixed serous glands*, in which a few mucous alveoli are intermingled with the serous, as the submaxillary.
3. *Mixed mucous glands*, in which the serous cells occur as crescentic groups or demilunes, as the sublingual and buccal.
4. *Pure mucous glands*, without serous alveoli or demilunes, as the palatal.

Simple alveolar or **saccular glands** in their typical flask-like form, as seen in the skin of amphibians, are not found in man. The dilated spherical fundus is lined with clear and distended secreting cells, in which the nuclei are displaced towards the periphery by the mucus elaborated within the epithelial elements. In the higher animals this type of gland is represented, somewhat modified, by the simple sebaceous follicles.

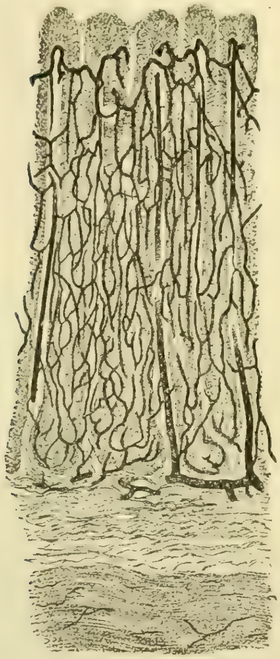
Compound alveolar or **saccular glands** constitute a group much less extensive than formerly supposed, since careful study of the form and arrangement of many organs, as the salivary glands, pancreas, etc., has shown that these are more appropriately regarded as tubo-alveolar than as branched saccular glands. The latter, however, still have representatives in the larger sebaceous and Meibomian glands. The most conspicuous example of the compound saccular or racemose type is the lung, which in its development and the arrangement of the air-tubes and the sac-like terminal compartments corresponds to this variety.

The **blood-vessels** distributed to glands are always numerous, since secretory activity implies a generous blood-supply. In the case of the smaller and simpler glands, the capillaries within the mucosa form a mesh-work outside the basement membrane enclosing the glandular epithelium. The large compound glands are provided with a vascular system which usually corresponds in its general arrangement to that of the excretory ducts, following the tracts of the interlobar and interlobular areolar tissue and its extensions between the groups of the alveoli. On reaching the individual acini, the capillaries form net-works which surround the basement membrane enclosing the alveoli, thus bringing the blood-current into close, but not direct, relation with the secreting cells, an arrangement favoring the selection by the protoplasm of the particular substances required for the function of the gland. When the relation between the glandular epithelium and the capillaries is unusually intimate,

as in the case of the liver, a distinct basement membrane is sometimes wanting, a delicate supporting reticulum alone intervening between the blood-stream and the protoplasm of the cells. Although subject to local deviations, conspicuously exceptional in the liver, the veins follow in general the course of the arterial branches, the larger blood-vessels, together with the main excretory ducts, the lymphatics, and the nerves, occupying the principal extension of the connective tissue into the glandular mass.

The **lymphatics** are represented by the larger trunks which follow the excretory ducts and freely anastomose within the interlobular areolar tissue. After the intralobular portion of the vessel is reached, its definite character is gradually lost until the lymphatic channels are to be recognized only as the clefts between the bundles of connective tissue separating the alveoli.

FIG. 1290.



Injected gastric mucous membrane, showing capillary net-work surrounding tubular glands. × 55.

FIG. 1291.

Section of submaxillary gland of rabbit; upper half of figure shows distribution of nerve-fibres to alveoli; lower half shows terminal ducts and secretion-capillaries. × 290. (*Retzius.*)

The **nerves** supplying the larger glands include fibres from two sources, the cranial or spinal nerves and the sympathetic. They follow the interlobular excretory ducts, around which plexuses are formed, ganglion-cells being frequent at the points of junction. The stronger twigs contain a preponderating proportion of thick medullated fibres, which become progressively less in size and number in their course towards the alveoli. Upon reaching the latter the nerves consist almost entirely of nonmedullated fibres, and in the end-plexuses around the alveoli such fibres alone are present. The terminal distribution, as demonstrated by the Golgi and methylene-blue methods, includes *epilemmar* and *hypolemmar fibrillæ*, the former lying upon and the latter beneath the basement membrane. The hypolemmar fibrillæ pass into the acini from the extra alveolar plexus formed by the filaments surrounding the basement membrane. The ultimate relation between the terminal fibrillæ and the glandular epithelium is still uncertain, but it may be regarded as established that the nerves extend between and around the cells; an intracellular termination, on the contrary, is doubtful. Retzius, Ebner, and others agree in picturing the delicate perialveolar plexus as consisting of tortuous and convoluted filaments which end in occasional

delicate varicosities. Arnstein[1] has described a special minute plate-like end-organ as a widely occurring mode of nerve-ending in glands. W. Krause[2] has noted in certain glands a form of end-capsule resembling a simplified Pacinian corpuscle. The sympathetic fibres are distributed especially to the involuntary muscle of the blood-vessels and the ducts, the peristaltic wave within the muscular coat of the latter facilitating emptying of the secretion.

Development.—Since glands are only extensions of the mucous membrane or integument upon which they open, their development begins as an outgrowth or budding from the epithelium covering such surfaces. In the simple tubular glands the minute cylinders are closely placed and composed of densely packed cells. In the case of the larger compound glands, as the salivary or pancreas, the first anlage consists of a solid cylindrical plug which, penetrating into the mesoblast, soon begins to branch. The ends of the terminal divisions enlarge and eventually become the alveoli. Meanwhile the surrounding mesoblast undergoes condensation and forms the interlobular and other septa, as well as the general envelope, or capsule, thereby giving definite form to the general glandular aggregation. The vascular and other structures usually found within the interparenchymatous tissue are secondary and later formations. The development of the gland involves a double process of active growth,—not only the extension of the epithelial processes, but also a coincident invasion and subdivision of the latter by the mesoblast to form the constituent units of the organ. The lumen of the gland appears first in the main excretory duct, from which it extends into the secondary tubes and, finally, into the alveoli. Growth, separation, and more regular arrangement of the cells composing the epithelial cylinders are the chief factors in producing the lumen. In the early condition of the glands, before the assumption of functional activity, the cells later constituting alveoli of the serous or mucous type are similar and without histological distinction. Upon the establishment of their different rôles, however, the characteristics distinguishing the varieties of glands appear, the differences depending upon physiological rather than upon inherent anatomical variation.

FIG. 1292.

Section of fœtal oral mucous membrane, showing developing tubo-alveolar gland. × 50.

[1] Anatom. Anzeiger, Bd. x., 1895.
[2] Zeitschrift f. rational. Med., Bd. xxiii., 1865.

THE ALIMENTARY CANAL.

THIS is a long and complicated tube extending from the mouth to the anus. Excepting the two ends, each of which is at first a pouch from the ectoblast, it is developed from the entoblast with a mesoblastic envelope. It consists of the *mouth*, *pharynx*, and *œsophagus* above the diaphragm, and of the *stomach* and *small* and *large intestines* below it. There are many accessory organs connected with it whose primary function is to assist in the process of nutrition. The chief ones above the diaphragm are the *teeth*, the *tongue*, and the *salivary glands;* those below it are glands of various kinds, mostly so small as to be contained in the mucous membrane. But two distinct organs, the *liver* and the *pancreas*, belong to this class, both being originally outgrowths from the gut. The *trachea* and *lungs* have a similar origin, but their physiological function is so different that they are treated of under a separate heading.

The general structural plan of the digestive tube, presenting in places great modifications, is : (1) a lining of mucous membrane ; (2) a submucous layer of areolar tissue, into which glands may penetrate from the former ; (3) a double layer of non-striped muscular fibres, of which, as a rule, the inner is circular and the outer longitudinal ; (4) below the diaphragm, a serous covering from the peritoneum, which, although originally complete, is in the adult wanting in certain parts.

The length of the alimentary canal is, on the average, not far from 9 m. (approximately 30 ft.), of which not more than 45 cm. (about 18 in.) is above the diaphragm. A preliminary sketch of the divisions above the diaphragm may be convenient. The *vestibule* of the mouth is the space between the lips and cheeks externally and the jaws and teeth internally. The (potential) cavity of the *mouth* is within the arches of the gums and teeth. It is bounded above by the *hard palate* and its backward continuation the *soft palate.* The greater part of the floor is occupied by the tongue. There is a free horseshoe-shaped space beneath the *tongue* within the lower jaw, called the *alveolar-lingual groove* or, better, the *sublingual space.* The *pharynx* joins the mouth at the *anterior pillar of the fauces*, a fold passing outward and downward from the soft palate to the tongue. The pharynx extends from the base of the skull to the lower border of the larynx. The upper part, the *naso-pharynx*, is behind the nasal chambers which open into it, the *oro-pharynx* is behind the mouth, and the *laryngo-pharynx* behind the larynx. At the lower border of the larynx it is followed by the *œsophagus*, a long tube which, piercing the diaphragm, opens into the stomach.

THE MOUTH.

The framework of the mouth is made by the hard palate and the alveolar processes of the upper jaw, by the greater part of the body (including the alveolar processes) of the lower jaw and part of the ramus, and by the hyoid bone, to which may be added the mylo-hyoid muscle forming the floor.

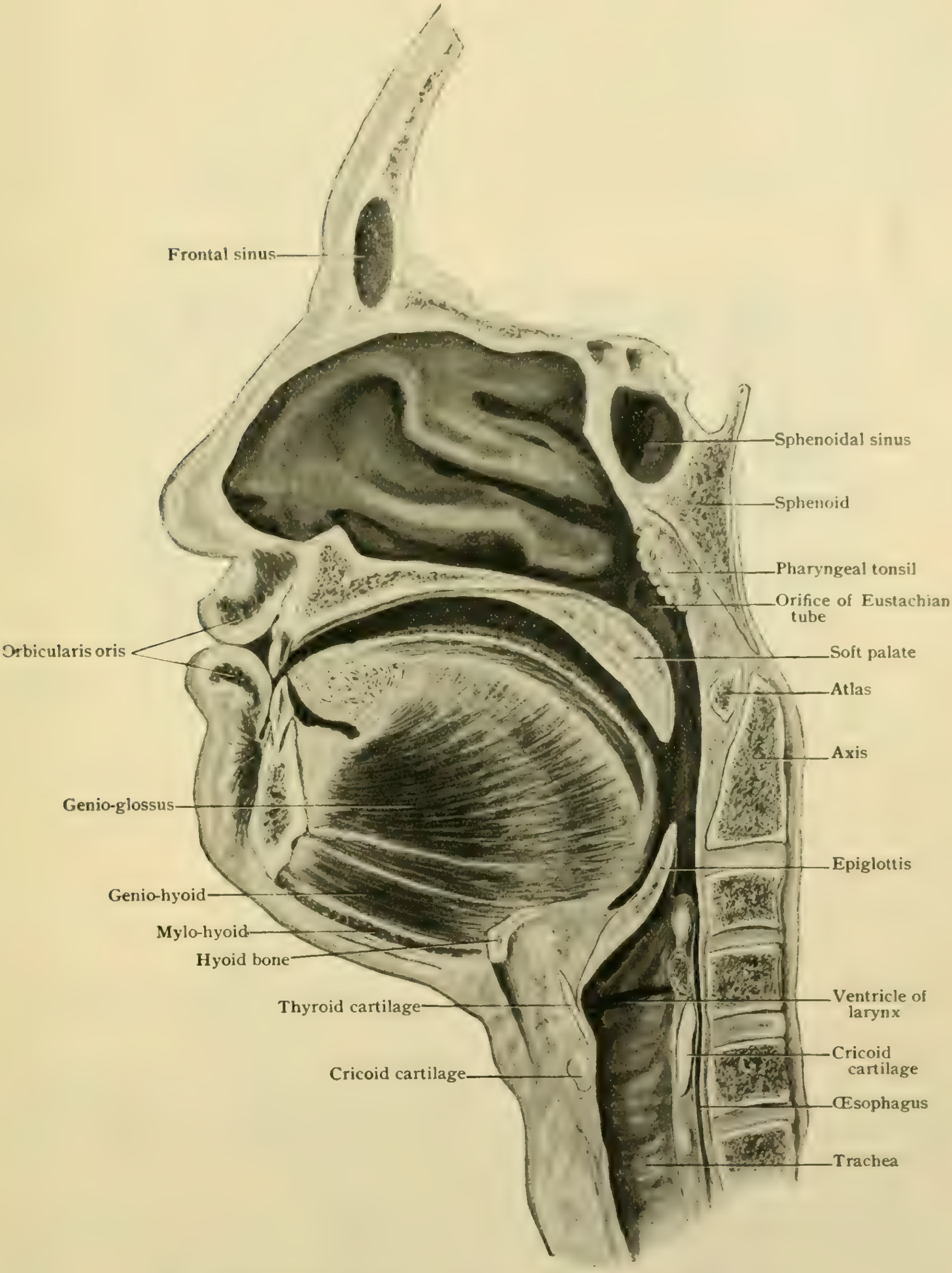
When the lips are opened and the lower jaw dropped, the mouth is a true cavity extending to the pharynx ; when these parts are closed, the tongue fills practically the whole space. It is convenient, however, to speak of the cavity of the mouth. This space is subdivided into the *vestibule* or *preoral cavity* and that of the *oral cavity* or mouth proper. The former is the region between the closed lips and cheeks in front and the closed jaws and teeth behind. When the lips are closed, it communicates with the mouth proper only by a small passage behind the wisdom-teeth, in front of the ramus of the jaw.

THE LIPS, CHEEKS, AND VESTIBULE.

The orifice of the mouth (**rima oris**) is a transverse slit of variable length, bounded by projecting folds,—the *lips.* These, like the *cheeks*, with which they are continuous, are composed of complicated layers of muscle, covered externally by skin and internally by mucous membrane.

Fat is found irregularly disposed among the muscles of the cheeks in varying quantity, but in the depression in front of the masseter and superficial to the buccinator there is a distinct ball of fat enclosed by a capsule, which is the remnant of the so-

FIG. 1293.

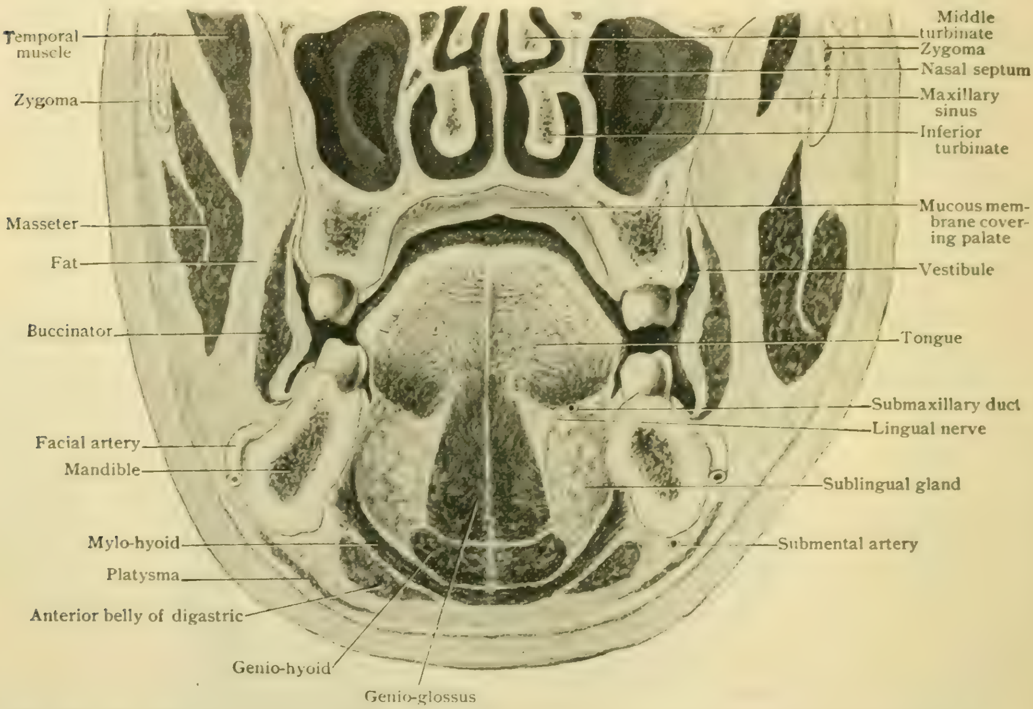


Sagittal section of head of young adult, three-fourths natural size.

called "button" of infancy,—a collection which gives resistance to the cheek and prevents it from being flattened by atmospheric pressure during nursing. The mucous membrane is reflected from the cheeks onto the jaws, where it covers the gums. This line of reflection at the middle of the lower jaw is 7 or 8 mm. from the alveolar

border and about twice as far from it in the upper. In both jaws, but especially in the lower, the line approaches the teeth as it passes backward. There is a distinct fold or *frenum* of mucous membrane passing from the anterior nasal spine to the middle of the upper lip. The free edge is often irregular, and may have a nodular enlargement. A much smaller fold is often found on each side in the region of the bicuspids. A median fold to the lower lip is small and inconstant. Externally the lips present a red region of modified mucous membrane, intermediate between the skin of the face and the mucous membrane of the mouth. A sagittal section through either lip shows these three parts. In the new-born the intermediate[1] part is subdivided into two, of which the inner—rather the broader—more closely resembles true mucous membrane than the latter. After death in the young child it assumes a brownish color, which has been mistaken for the effect of acid. In the adult these two subdivisions lose their distinctness. The lower lip is the larger and

FIG. 1294.



Frontal section, showing oral cavity and lower part of nasal fossæ; plane of section passes through anterior end of zygoma. Three-fourths natural size.

fuller, showing more red except towards the angles of the mouth, where it disappears. Its lower border is slightly indented in the middle. The upper lip shows a more marked indentation below a little gutter, the *philtrum*, running down from the nasal septum. A slight median prominence of the lower edge of the upper lip is the *tubercle*, which interrupts the straightness of the cleft when the lips are closed, making the line resemble a Cupid's bow.

The **muscles of the lips** are a complicated interlacement from many sources. The *orbicularis oris*, formerly supposed to form a sphincter, has no separate existence. The general plan is as follows. The upper fibres of the buccinator enter the lower lip and pass out at the opposite angle to ascend into the upper part of the other buccinator. Those of the lower part traverse the upper lip in a similar manner. The layer formed by the buccinator lies under the mucous membrane near the border of the lips, and bends forward so that its edge is nearest the skin at about its junction

[1] Otto Neustatter : Ueber den Lippensaum, etc., Inaug. Dissert., Munich, 1894.

with the free red surface. In the lower lip the *quadratus* (depressor labii inferioris) runs upward under the skin to break up into fibres ending in the lips. The *triangularis* (depressor anguli oris) passes at the angle of the mouth into the upper lip and ends as a series of separate fibres inserted into the mucous membrane, many of them crossing the middle line. This muscle, before it breaks up, is in the same plane as the buccinator, but farther from the edge of the lips. Some German authors, by grouping together the various muscles of the upper lip, have made a *superior quadratus* and *triangularis* which are disposed in a similar manner to the lower ones. Besides these there are two muscles, the zygomaticus, descending, and the risorius, ascending, which meet at the oral angles and end there in the skin or mucous membrane, or in both. There are also numerous fibres, seen only with the microscope in sagittal sections, passing from the skin to the mucous membrane ; these constitute the *rectus*.[1]

FIG. 1295.

Labial region, from life, reduced one-fifth.

FIG. 1296.

Sagittal section of lip of young child. × 20.

The **mucous membrane,** which is smooth, is so closely attached to the muscles that it follows the movements of the latter. Mucous glands are lodged in its

[1] Aeby : Archiv f. mikro. Anat., Bd. xvi., 1879.

deeper parts and in the scanty submucous tissue. They are named *labial*, *buccal*, and *molar*, according to their situation. The *labial glands* are gathered into a series of groups near the inner border of the lips, the *buccal glands* are smaller and scattered, and the *molar glands* are well-defined groups opposite the molar teeth. The duct of the parotid gland (*q.v.*) opens into the vestibule, the space between the lips and cheeks externally, and the teeth and alveolar processes internally. Separating the vestibular space from that of the mouth proper behind the alveolar processes is a prominent fold of mucous membrane over the pterygo-maxillary ligament. This fold appears at the inner side of the last upper molar and runs downward and outward to that of the lower. The space behind the teeth when the mouth is closed is small, but a tube some 5 mm. in diameter can be passed through it.

Vessels.—The *arteries* supplying the lips, which are very vascular, are chiefly the coronary branches of the facial arteries, each of which forms an arch meeting its fellow in each lip. The vessel lies between the muscles and the glands of the mucous membrane, nearly opposite the line of junction of the latter and the intermediate portion. The pulsation is easily felt through the mucous membrane. The *veins*, less regular, lie on the outer side of the muscles. The *lymphatics* empty into the glands at the angle of the jaw, excepting those near the median line of the lower lip, which run into the suprahyoid glands.

Nerves.—The mucous membrane of the cheek is supplied by the buccal branch of the inferior maxillary division of the fifth cranial nerve, the lips by the terminal branches of its second and third divisions.

THE TEETH.

In form the teeth present three parts,—the *body* or *crown*, coated with enamel ; a somewhat constricted part, the *neck*, covered by the gums ; and the *root* or *fang*, which, covered by the cementum, is fixed in the socket. The greater part of the tooth is composed of the dentine and surrounds the *pulp-cavity*, to which minute openings in the root or roots transmit vessels and nerves.

The shape of the crowns is the basis of classification. Thus, in the front teeth the crown is flattened so as to have a chisel-like shape, adapted to cutting, hence these are termed *incisors ;* the *canine* teeth have the crown forming a single point or cusp ; the *bicuspids* have two, and the *multicuspids*, or *molars*, several cusps. The crowns of all the teeth may be considered as modifications of a simple cone, or as combinations of several cones.[1]

In man the teeth come in two sets, the *temporary* or *milk* and the *permanent teeth ;* the total number of the former is twenty, that of the latter thirty-two. The number and arrangement of the teeth of any animal is expressed in its *dental formula ;* this for man, for the left half of the mouth, may be written as follows :

$$\text{Temporary Teeth: } i\,\frac{2}{2}\;c\,\frac{1}{1}\;\;\;m\,\frac{2}{2}\left(=\frac{5}{5}\times 2=20\right).$$

$$\text{Permanent Teeth: } i\,\frac{2}{2}\;c\,\frac{1}{1}\;bi\,\frac{2}{2}\;m\,\frac{3}{3}\left(=\frac{8}{8}\times 2=32\right).$$

It will thus be seen that in the milk-teeth there are no bicuspids and one molar less.

Since the typical mammalian dental formula is $i\,\frac{3}{3}\;c\,\frac{1}{1}\;bi\,\frac{4}{4}\;m\,\frac{3}{3}$, it may be assumed that in man three pairs have been suppressed. These suppressed teeth are occasionally represented by supernumerary ones ; from the position of the latter it is probable that the missing teeth are the second incisors and the first and fourth bicuspids.

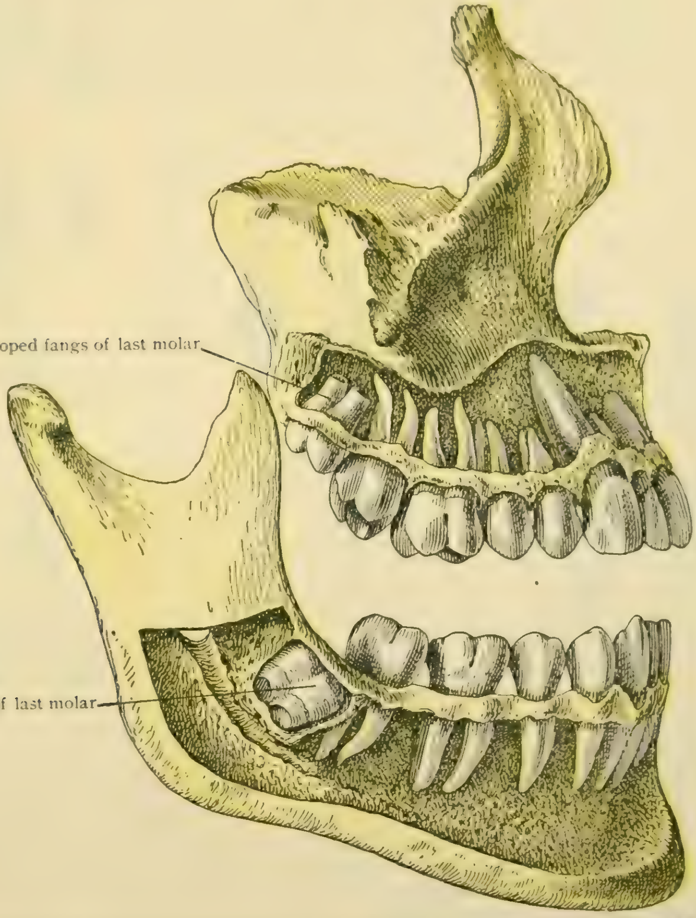
To avoid confusion in the nomenclature of the teeth from the curve of the jaws, it is customary to speak of the *labial* and *lingual* surfaces of the incisors and canines, and of the *facial*, or *buccal*, and *lingual* surfaces of the bicuspids and molars. The sides against the other teeth are often called the median and distal, supposing the teeth to be implanted in a straight transverse line. This is not satisfactory in all

[1] See Homologies, page 1566.

cases. We shall speak instead of the inner and outer sides of the incisors and canines and of the anterior and posterior sides of the bicuspids and molars. If the position of the tooth in the jaw be remembered, no confusion is possible.

The Incisors.—The *crowns* are characterized by slightly convex quadrilateral labial surfaces, rather broader than the lingual ones, and ending in straight cutting edges, slightly concave lingual surfaces slanting forward and bevelled at the edge, triangular lateral surfaces, and single roots. The labial and lingual surfaces of the crowns are bounded at the root by curved lines, the convexity being towards the gums. At the sides these borders are continued as straight lines towards the free

FIG. 1297.



Permanent teeth, showing their forms and relations; outer surface of jaws partly removed. Last molars are only partially formed.

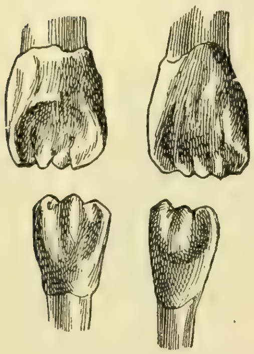
edge, and meet at an acute angle. The enamel is continued farther on the lingual surface, especially in the lateral incisors of both jaws. The cutting edge shows three small scallops on its first appearance, but they speedily wear away (Fig. 1298).

The **superior median incisors** are much the largest. The labial surface of the crown is nearly square. The inner half of this surface is more strongly convex than the lateral. Traces of three swellings are often found on the labial side of the lower half of the crown extending to the three primitive scallops on the edge. The free edge meets the internal border at nearly a right angle, but the outer angle is rounded. The lingual surface, narrower than the labial, is a little concave. Sometimes the edges are raised so as to leave a distinct V-shaped depression, in the middle of which runs a vertical ridge, the *cingulum*, which ends below in a *tubercle*.

Often the cingulum of the incisors is represented merely by the tubercle. There are all kinds of intermediate stages between this and a nearly plane surface. Sometimes the tubercle is triple. The fang is nearly conical, and usually has an outward slant. The *superior lateral incisors* are more cusp-shaped, the angles, especially the outer, tending to be rounded. The lingual surface is less plane than in the median incisors and the cingulum larger. Sometimes it is almost a distinct cusp. The fang is also conical, with an outward inclination.

The **inferior incisors** are smaller than the superior, and the median ones the smallest of all. The *crowns* broaden from the neck to the edge. This feature is more marked in the lower races, and still more in apes. The labial surface is more nearly plane than in the upper ones; the lingual surface is more even. The cingulum is small, often not very evident. The angles of the free edge are sharper than those of the upper jaw, excepting the outer one of the lateral tooth, which is generally rounded. The *fangs* are compressed from side to side and their tips turn a little away from the median line. This is particularly true of the lateral one, but

FIG. 1298.

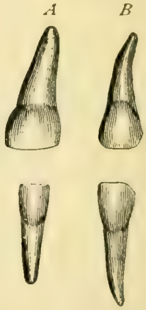


Unworn surfaces of upper and lower permanent incisor teeth, lingual aspect. × 2.

FIG. 1299.

Median incisor teeth of left side, labial (*A*) and lateral (*B*) aspects. (*Leidy.*)

FIG. 1300.



Temporary incisor teeth of left side. *A*, median; *B*, lateral incisors. (*Leidy.*)

is a constant feature of neither. The sides of the fangs are often grooved. The external groove is the deeper, and when only one is present it is on that side.

The *pulp-cavity* is relatively large in the superior median incisors, in which it presents three expansions towards the free edge. It is smaller in the others, and has usually but two distinct diverticula. The canal of the lower teeth, especially when the roots are deeply grooved, often divides below the pulp-cavity into an anterior and a posterior branch, which usually reunite before reaching the tip of the fang.[1]

The upper incisors occupy in all more space than the lower, which is due chiefly to the great size of the upper median ones. In the lower jaw the median incisors are the smaller, but there is no great difference between them and the laterals. The superior laterals are but slightly larger than those below them.

The **temporary incisors** differ only slightly, save in size, from the permanent ones. The edges, however, are originally straight, except those of the inferior median ones, which show the irregularities.[2]

The Canines.—These, called by the Germans the "corner teeth" as marking the point where the alveolar arch changes direction most suddenly, are characterized by a crown with a single cusp, a long conical root somewhat compressed laterally and marked by a groove on each side. The *crown*, convex on the labial side, expands

[1] Mühlreiter: Anatomie des Menschlichen Gebisses, Leipzig, 1891.

[2] Zuckerkandl: Anatomie der Mundhöhle, mit besondere Berücksichtigung der Zähne, Wien, 1891.

from the root and suggests that of an incisor with the angles taken off. The lingual side of the crown of the upper tooth tends to be convex, often having a ridge running down to the small tubercle at the base. In the lower tooth this side is plane or concave, with a distinct tubercle, which exceptionally is enlarged so as to hint at a secondary cusp. The sides of the crown are triangular. The borders of the enamel are convex to the gum on the labial side, less so on the lingual, and slightly concave laterally. The *fang* of the upper tooth is the longer and the less compressed ; it very rarely ends in a bifurcation, but this is less uncommon in the lower. The direction of the end of the fang is uncertain. The whole tooth is broader on the labial than on the lingual side. The *pulp-cavity* is most marked in antero-posterior sections, which show an enlargement of its continuation at the beginning of the root, just beyond the neck.

FIG. 1301.

Canine teeth of left side, labial (*A*) and lateral (*B*) aspects. *C*, temporary canines. (*Leidy*.)

The **milk canines** are much like the second ones, only smaller. The labial surface of the upper tends to divide into an outer and an inner facet. The root is approximately triangular on section, with rounded edges.

The Bicuspids or Premolars.—These teeth, of which the second is the larger in both jaws, are characterized by *crowns* with two cusps, one on the buccal and one on the lingual side. The upper ones, being very much the more typical, will be used for the general description. Both the labial and the lingual aspects of the crowns are convex ; they expand laterally from the neck, and each ends in a pointed cusp of which the anterior border is the shorter. This is used in determining the side, but we agree with Testut that the guide is often useless. The buccal cusp is the larger. The cusps are separated by a furrow from which small ramifications often run onto the buccal one. The lingual cusp has an unbroken surface. The buccal cusp of the first bicuspid is more prominent than the lingual, but in the second they reach the same plane. The border of the enamel is convex towards the root on both the buccal and lingual aspects, the ends of these curves meeting on the other sides. The *fang* is compressed with a groove on the sides next its neighbors. That of the second is often bifid just at the tip, but that of the first is very often, perhaps usually, divided into two throughout, having a buccal and a lingual root. Sometimes the former is subdivided, so that it has three like a molar. The root has in general a backward slant.

The **lower bicuspids** have smaller grinding surfaces on the crowns than the upper, but the roots are longer, and the crowns, seen from the side, are at least as large. The first has a well-developed buccal cusp, curving in from the buccal surface, and a very small lingual one connected to the former by a ridge interrupting the fissure between them, which gives the tooth something of the effect of a small canine. The second, like that of the upper jaw, has the two cusps in one plane ; the lingual one is sometimes double, and the plane is often obscure. The flattened fang is but faintly grooved, if at all, and is rarely bifid.

FIG. 1302.

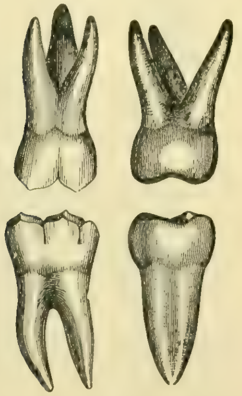
First premolar teeth of left side, labial (*A*) and lateral (*B*) aspects. (*Leidy*.)

The *pulp-cavity* of the bicuspids ends in an expansion below each cusp, that under the buccal being the larger. In the upper teeth the cavity is much compressed from side to side in the root. In the first upper bicuspid there are usually two prolongations to the point of the fang, even when the root is not split. In the second the cavity generally agrees with the conformation of the root. In the lower teeth the cavity is less compressed and is tolerably roomy as it enters the root. It is usually single, but may split.

The Molars.—These teeth—three on each side—are distinguished by the large crown, into which the neck expands, the number of cusps on the surface, and the greater subdivision of the root. Those of the lower jaw are the larger; and in both jaws the first is the largest and the last (called from its late appearance the *wisdom-tooth*) the smallest. The *crowns* are convex on both the buccal and lingual sides, but nearly plane on the others. The enamel ends in a nearly straight line all the way round. The grinding surfaces are four-sided; those of the upper are somewhat diamond-shaped, the buccal anterior angle being rather in front; those of the lower are nearly parallelograms, the long diameter being antero-posterior. Typical upper molars have four cusps at the angles; typical lower ones have an additional cusp at the posterior border; but in the upper jaw the first is the only one that can be called typical.

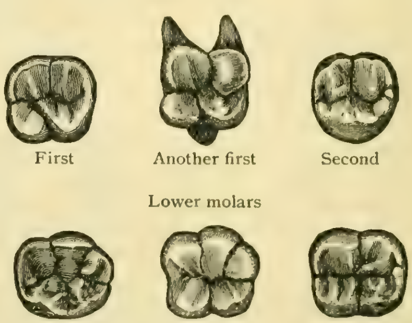
In the **upper molars** the largest cusp is the anterior lingual, which is connected by a ridge (the cingulum) to the posterior buccal. The posterior lingual cusp is the smallest. A minute rudimentary cusp is found on the lingual surface of the anterior lingual cusp, usually too small to reach the grinding surface, and often hard to recognize. Not counting this, the first upper molar has four cusps in more than 90 per cent. Owing to the cingulum, the grooves on the grinding surface are best described as two oblique ones, the first from the anterior border to the middle of the buccal, the second from the lingual border to the middle of the buccal. They are deepest at the middle. They appear on the buccal and lingual sides, deeper on the former, but rarely reach the gum. They may end in a pit, a favorite seat of caries (Tomes). The crown of the second upper molar presents three chief forms (Mühlreiter). It may have four cusps and differ but slightly from the first molar. The lingual surface is relatively narrower and the posterior lingual cusp smaller. In the second form the last-mentioned cusp is wanting. The cingulum persists and the grinding surface is approximately triangular. The third form is compressed from side to side into a very narrow diamond, with the anterior buccal cusp in front and the posterior lingual behind. Three and four cusps are about equally common in this tooth in Caucasians, but the lower races have more often four. The crown of the upper wisdom-tooth presents many remarkable variations. The posterior lingual cusp is wanting in about two-thirds of the cases. The crown may be strongly compressed, as has been described for the second molar, but with greater variation. In size the wisdom-tooth may be very large or very small.

FIG. 1303.



Second molar teeth of left side, labial (*A*) and lateral (*B*) aspects. (*Leidy.*)

FIG. 1304.



Triturating surfaces of molar teeth of right side. The upper margin of the figures corresponds to the labial surface. (*Leidy.*)

The *crowns* of the **lower molars** are divided by a crucial fissure, the main line running antero-posteriorly. The hind part of this splits so as to enclose the fifth cusp, which is near or actually at the buccal side. The effect of this is to form a cavity at the crossing of the lines in the middle of the crown. The lines on the sides

of the crowns are less deep than in the upper jaw. Sometimes the fifth cusp is wanting, in which case the posterior part of the furrow does not divide and the arrangement is remarkably symmetrical. Very rarely the first molar has a sixth cusp on the lingual side. The first molar has five cusps in more than 90 per cent.; the second four only in more than 80 per cent.; the third four rather more often than five. The buccal cusps of the lower molars are worn down earlier than the lingual ones.

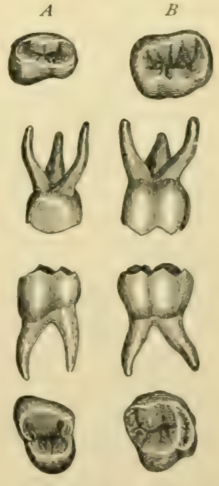
The following tables from the independent researches of Röse[1] and of Zuckerkandl show the percentage of frequency of different groupings of cusps. Although there is some discrepancy in the percentages, both agree as to the most and least common arrangement in both jaws. These statistics, like those of the separate teeth, apply to Europeans. (It is to be remembered that a certain percentage of teeth cannot be included.)

Upper Jaw.	Molars.			Per Cent.	
	1	2	3	Röse.	Zuck.
Cusps	4	4	4	19.9	9.6
Cusps	4	4	3	28.9	28.7
Cusps	4	3	3	37.9	60.1

Lower Jaw.	Molars.			Per Cent.	
	1	2	3	Röse.	Zuck.
Cusps	5	5	5	19.8	11.5
Cusps	5	4	5	30.4	30.5
Cusps	5	4	4	40.4	50.0

The *fangs* of the first and second upper molars are two buccal and one lingual, which latter is much the largest. It is often, especially in the first molar, grooved on the lingual side. It is conical and strongly divergent. It often shows a tendency to subdivision, which may actually occur, although rarely. The two buccal ones are compressed antero-posteriorly and nearly vertical. The front one is the broader, and is grooved before and behind. This is often the case with the other. The roots of the upper wisdom-tooth are smaller; the lingual is less divergent, and may be connected by a plate with one of the buccal ones. All may be fused more or less completely into one. The roots of the inferior molars are two: an anterior and a posterior, of which the former is rather the larger, both compressed from before backward and, especially the first, deeply grooved, suggesting the fusion of two. Sometimes, again especially in the first, each root is bifid. Those of the wisdom-tooth are usually nearer together, and are frequently fused into a common conical root. Apart from their position in the jaws, the roots of the molars, excepting the upper wisdom-tooth, have a backward slant of varying degree. Their twists and curves are remarkably uncertain. Sometimes they converge and sometimes diverge unduly, hooking in either case under bone, so as to make extraction difficult or impossible. The *pulp-cavity* of the molars is large, especially at the level of the neck. In the upper teeth it is distinctly wider transversely than from before backward. It has as many prolongations towards the surface as there are cusps. There is a canal in each root of the upper teeth. Those in the buccal fangs are compressed, that in the lingual cylindrical. The anterior fang of the lower molars has two canals which develop from a single one. The posterior fang has but one.

Fig. 1305.



Temporary molar teeth (*A*, first; *B*, second) of left side. Triturating surfaces of crowns also shown. (*Leidy*.)

The **milk molars** are two in number. Like the permanent ones, the lower are the larger; but, unlike them, the second tooth is larger than the first in both jaws. The crown of both first molars presents a prominence on the buccal surface near the root. The crown of the first upper molar is rather suggestive of a bicuspid, although there are two buccal cusps and one lingual. The first inferior molar is relatively narrow and long from before backward. The length of the buccal side is greater than that of the second permanent one. The second molars resemble very closly the first permanent ones. The upper has four cusps and a cingulum, the lower five cusps. The hollow in the crown of the temporary molars is relatively deeper than that of the permanent ones, but smaller and more divergent. They straddle the crowns of the developing bicuspids.

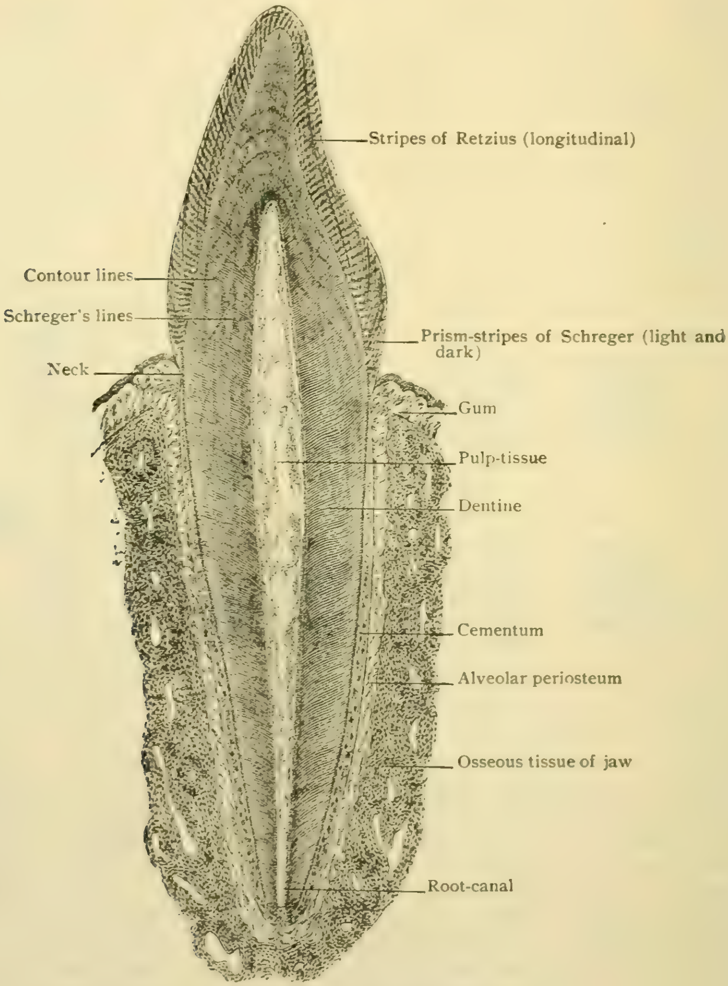
[1] Anatom. Anzeiger, Bd. vii., 1892.

TOOTH-STRUCTURE.

In principle, and among the lower vertebrates in fact as well, teeth may be regarded as hardened papillæ of the oral mucous membrane; they consist, therefore, of two chief parts,—the connective-tissue core and the epithelial capping. Of the three constituents present in typical mammalian teeth, the enamel is the derivative of the ectoblastic epithelium, the dentine, with the pulp, and the cementum being contributions of the embryonal connective tissue.

The Enamel.—This, the hardest tissue of the body, covers the crown, being thickest on the cutting edge or grinding surface of the tooth. It gradually thins away

FIG. 1306.

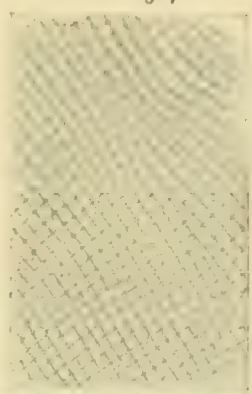


Sagittal section of canine tooth *in situ*. Semi-diagrammatic.

towards the neck, around which its terminal border appears as a more or less distinct and often serrated edge. The external surface of the enamel, especially in young teeth, often exhibits a fine striation composed of horizontally disposed lines. Under a hand-glass these lines are seen to be minute elevations, the *enamel-ridges*, which encircle the crown. The remarkable hardness of this tissue is due to the large amount (97 per cent.) of earthy material and the small proportion of organic matter, which latter in adult enamel averages only about 3 per cent.; in infantile enamel the amount of animal material is from five to six times greater (Hoppe-Seyler).

The enamel—the product of epithelial cells, the *ameloblasts*—consists of an aggregation of five- or six-sided columnar elements, the *enamel prisms*, which measure from .0035–.0045 mm. in diameter and from 3–5 mm. in length. Their general disposition is at right angles to the surface of the dentine upon which they rest, on the one hand, and to the exterior of the crown on the other. They usually extend the entire thickness of the enamel, and are of slightly larger diameter at the surface of the tooth than next the dentine, in this manner compensating for the increase in the external circumference of the crown. The assumption that additional prisms are intercalated at the periphery is not supported by the manner of the production of the enamel-columns. The latter run for a short distance almost at right angles to the surface of the dentine, then bend laterally for a considerable part of their course, but assume a vertical disposition on approaching the external surface. In addition to these general curves, the ranges of enamel-columns possess a spiral arrangement, in consequence of which the parallelism of the prisms, as seen in ground-sections, is disturbed and their bundles are apparently interwoven.

FIG. 1307.



Ground-section of enamel, showing ranges of enamel-prisms. × 500.

In thin accurately transverse sections enamel presents a mosaic in which the hexagonal areas represent the ends of the individual prisms. Critically examined, the areas consist of a darker central portion surrounded by a narrow lighter peripheral zone. The interpretation of the latter has been various, many observers regarding such lines as cement-substance holding together the prisms. According to Walkhoff,[1] however, what is usually regarded as cement-substance is a cortical, apparently homogeneous layer of less thoroughly calcified material which encloses the denser central portion of the prism and acts as a cushion, thereby reducing the effect of pressure. After the decalcifying action of acids, the prisms may be outlined by stains which color the very meagre amount of true cement-substance which exists between the enamel-columns and appears as delicate lines defining the prisms.

Under favorable conditions, especially, but not only, after the action of acids, the enamel-prisms exhibit alternate light and dark transverse markings. The true relations of these bands are to be appreciated only by accurate focusing in thin sections passing exactly parallel to the axes of the prisms ; otherwise the obliquity of section produces the optical distortions often represented in the assumed wavy contour of the enamel-rods. The varicose appearances commonly seen depend upon the beaded form and consequently scalloped border of the denser central portion of the prisms, which give a corresponding arrangement to the lighter cortical substance which fills the minute inequalities of that portion ; the true outline of the enamel-prism, however, is smooth and straight, and not varicose, as the optical impressions lead one to believe and as usually pictured. According to Williams, the apparent varicosities depend upon the spherical form of the enamel-globules of which the prisms are built up.

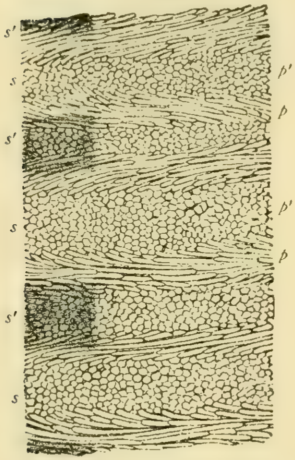
When an axial longitudinal section of a tooth is examined by reflected light, the enamel displays a series of alternate dark and light bands,—the *prism-stripes of Schreger*. These markings extend generally vertical to the surface of the enamel, and depend upon the relation of the ranges of the enamel-prisms to the axes of the light-rays. Rotation of the illuminating pencil through 180° effects the change of the dark stripes to light ones and *vice versa*. Each stripe includes from ten to twenty enamel-prisms, and is invisible by transmitted light.

In addition to the foregoing markings, the enamel often presents, in radial longitudinal sections, brownish parallel lines, the *stripes of Retzius*, which run in the general direction of the contour of the tooth, but at an angle of from 15° to 30° with the free surface. Seen in sections cut at right angles to the tooth-axis, these stripes appear as a series of concentric lines encircling the crown parallel to and near the surface ; in the middle and deeper parts of the enamel they are less evident or entirely

[1] Normale Histologie mensch. Zähne, 1901.

absent. The interpretation of the stripes of Retzius is still a subject of dispute. The brown appearance of the stripes by transmitted light only, by reflected light appearing bluish white, disproves the assumption that they depend upon the presence of pigment within the enamel. The widely accepted view of Ebner, that the stripes are due to air contained in the interfascicular clefts, has been modified by Walkhoff, who regards the markings as due to local diminution in the calcification of the enamel-prisms during certain periods in the growth of the tissue when the central as well as the cortical substance of a great number of columns fails to take up sufficient lime salts.

FIG. 1308.



Longitudinal ground-section of enamel, treated with acid, showing disposition of ranges of enamel-prisms (p, p') in stripes of Schreger. Left third of figure shows alternate light (s) and dark (s') bands as seen by reflected light. × 200. (*Ebner.*)

The *enamel-cuticle*, or *membrane of Nasmyth*, forms a continuous investment of the crown of the newly erupted tooth. In the course of time it disappears from the areas exposed to wear, but over the protected surfaces it may persist during life. The membrane (.009–.018 mm. in thickness) is transparent and remarkably resistant to the action of acids, less so to alkalies, affording admirable protection to the underlying enamel. After separation from the latter by acids it appears structureless, or at most granular. The inner surface of the membrane presents markings and slight irregularities which correspond to the free ends of the subjacent enamel-prisms.

The origin of the enamel-cuticle has been much discussed, and even now is not without some uncertainty. It may be regarded as established that it represents the remains of part of the tissue once concerned in the production of the enamel. The latter is formed, as more fully described on page 1561, through the agency of the epithelial cells constituting the inner layer of the enamel-organ. With the completion of their task as enamel builders, these cells produce a continuous cuticular envelope which persists as Nasmyth's membrane, the epithelial elements of the enamel-organ, so far as they are concerned in forming enamel, subsequently degenerating. The enamel-cuticle is continuous with the cortical substance of the prisms, with which it agrees in optical and chemical properties,—a relation which confirms the identity of origin of Nasmyth's membrane and the enamel-columns.

The Dentine.—The dentine or ivory resembles bone both in its genesis and chemical composition, being a connective tissue modified by the impregnation of lime salts. Dentine exceeds bone in hardness, containing a larger proportion (72 per cent.) of earthy matter and a smaller amount (28 per cent.) of organic substance. When decalcified by acids, the remaining animal material retains the previous form of the dentine and yields gelatin on prolonged boiling. Dentine, like bone, is formed through the agency of specialized connective-tissue cells, the *odontoblasts*, but differs from osseous tissue in the small number of these cells which become imprisoned in the intercellular matrix. When this occurs, as it exceptionally does in normal human dentine and more frequently in pathological conditions or in the lower animals, the *dentine-cells* correspond to the bone-corpuscles, both being connective-tissue elements lying within lymph-spaces in the calcified intercellular substance.

Examined in dried sections under low magnification, the dentine presents a radial striation composed of fine dark lines which extend from the pulp-cavity internally to the enamel or the cementum externally. These dark lines are the *dentinal tubules* filled with air, which are homologous with the lacunæ and canaliculi of bone, and contain the processes of the odontoblasts. In the crown, as seen in longitudinal sections, the course of the dentinal tubules is radial to the pulp-cavity; in the root their disposition is horizontal and almost parallel. The canals, however, are not straight, but sigmoid, the first convexity being directed towards the root, the second towards the crown. In addition to these *primary curves*, which are especially marked in the crown, the dentinal tubules present numerous shorter *secondary curves* which

impart to the individual canaliculi a spiral course. The cause of the latter Kollmann refers to the more rapid growth of the dentinal fibres than of the slowly forming dentinal matrix. In consequence of the correspondence of the curvature of the dentinal tubules, the tooth-ivory exhibits a series of linear markings, *Schreger's lines*, which run parallel to the inner surface of the dentine. These markings must not be confounded with the contour lines of Owen (page 1552), also within the dentine, or with Schreger's prism-stripes within the enamel (Fig. 1306).

The *dentinal tubules* are minute canals, from .0013–.002 mm. in diameter, which begin at the pulp-cavity with the largest lumen and extend to the outer surface of the dentine, to end beneath the enamel or cementum. Each spirally coursing canal undergoes branching of two kinds, a dichotomous division at an acute angle in the vicinity of the pulp-cavity, resulting in two canaliculi of equal diameter, and a lateral branching during the outer third of their course whereby numerous twigs are given off with a corresponding diminution in the size of the canaliculi; the terminal tubes, often reduced in diameter to mere lines, frequently anastomose with one another or form loops. The dentinal tubules are occupied by the delicate *dentinal fibres*, the processes of the odontoblasts, which in the young tooth constitute a net-work of protoplastic threads throughout the dentine of importance for the nutrition of the tissue. The relation of the dentinal tubules on the external surface of the dentine varies on the crown and root. In the former situation the free surface of the dentine presents crescentic depressions, filled by the enamel, in which the tubules appear as abruptly terminating or cut off; on the root, on the contrary, where the dentinal surface is smooth, the tubules stop in curved ends or loops beneath the cementum, only in very exceptional cases communicating with the canaliculi of the latter.

FIG. 1309.

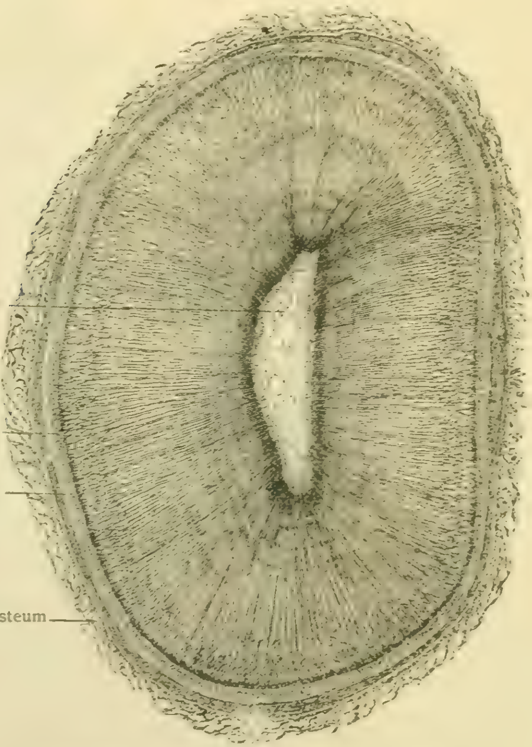
Ground-section of dried tooth including adjacent enamel and dentine. × 300.

The immediate wall of the dentinal tubules is formed by a delicate membrane, the *sheath of Neumann*, which in appropriate transverse sections appears as a concentric ring. On softening the decalcified dentine by acids or alkalies, the sheaths may be isolated, since they resist the action of the reagents which attack the surrounding intertubular substance. The sheaths of Neumann are formed through the agency and at the expense of the dentinal fibres, the latter being smaller in old than in young dentine. The sheaths, therefore, may be regarded as specialized parts of the intertubular matrix, distinguished by less complete calcification and greater density.

The intertubular *ground-substance* of dentine resembles that of bone in being composed of bundles of extremely delicate fibrillæ of fibrous connective tissue. The latter, best seen in decalcified tissue, swell on treatment with water containing acids or alkalies, and yield gelatin after prolonged boiling. The disposition of the bundles

of fibrillæ—more regular in dentine than in bone—is longitudinal and parallel to the primary surfaces of the dentine. In addition to the fibres which extend lengthwise, others run obliquely crosswise in the layers of dentine. The bundles of fibrillæ measure from .002–.003 mm. in diameter, and appear in transverse sections as small punctated fields. The fibrillæ are knit together by the calcified organic matrix, in which the lime salts are deposited in the form of spherules, the interstices between which are later filled and calcification thus completed. When, as often happens, the latter process is imperfect, irregular clefts, the *interglobular spaces*, remain, the contours of which are formed by the spheres or *dentinal globules* of calcareous material. The interglobular spaces are of irregular form and uncertain extent, being usually largest in the crown. At the border between the dentine and the cementum there exists normally a distinct zone, the *granular layer of Tomes* (Fig. 1311), composed of

FIG. 1310.



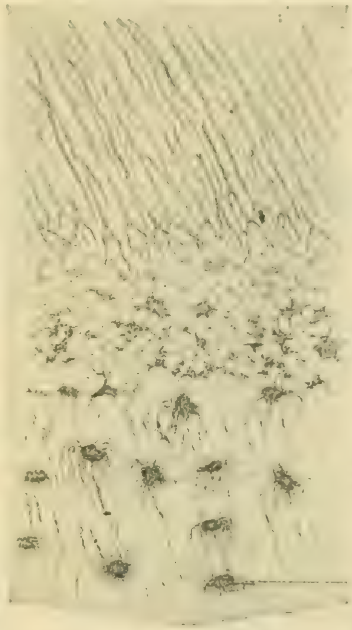
Transverse section of root of lower canine tooth. × 30.

closely placed interglobular spaces of small size ; under low magnification in ground-sections the spaces appear as dark granules, hence the designation of the zone. Since the existence of these spaces depends upon imperfect calcification of the intertubular ground-substance, the dentinal tubules are unaffected and pass through the spaces on their course to the surface of the dentine, several of the canals traversing the larger spaces. The *contour lines of Owen*, or the *incremental lines of Salter*, appear as linear markings, which usually run obliquely to the surface of the dentine (Fig. 1306). They probably depend upon variations in calcification incident to the growth of the dentine, and resemble the interglobular spaces in their origin. The contour lines are best marked in the crown and are only exceptionally seen in the fang. As pointed out by Walkhoff, the lines of Owen and those of Retzius in the enamel are usually present at the same time, since both are expressions of imperfect calcification.

The Cementum.—The cement, or *crusta petrosa* of the older writers, forms an investment of slightly modified osseous tissue from the neck of the tooth to its

apex. Beginning where the enamel ceases, or overlapping the latter to a small extent, as a layer only .02–.03 mm. thick, the cement gradually increases in thickness until over the root, especially between the fangs of the molars, its depth reaches several millimetres. When well developed the cement usually presents two layers,—an inner, almost homogeneous stratum next the dentine, in which the cement-cells are absent, and an outer supplemental layer which exhibits the appearance of true bone-tissue. The ground-substance of cementum differs from that of ordinary bone in containing, according to Bibra, slightly less organic matter and a great number of fibre-bundles that extend vertically to the lamellæ, corresponding to Sharpey's fibres. The lacunæ are larger than those of bone and vary greatly in their number and form ; their processes, the canaliculi, are unusually long and elaborate. As in bone, so these lymph-spaces contain connective-tissue cells, the *cement-corpuscles*. The lamellæ are so disposed that the lacunæ lie generally parallel with the long axis of the tooth, their processes extending vertically to the free surface. While connecting with one another by means of the canaliculi, the lacunæ very rarely communicate with the dentinal tubules, the latter terminating in blind endings. The union between the outer surface of the cement and the pericementum is intimate, since the latter is in fact the alveolar periosteum from which the cement was derived ; this close relation is indicated by the roughness which the outer surface of the cement presents when macerated. Although at times feebly developed under normal conditions, typical Haversian canals are found only in conditions of hypertrophy.

FIG. 1311.



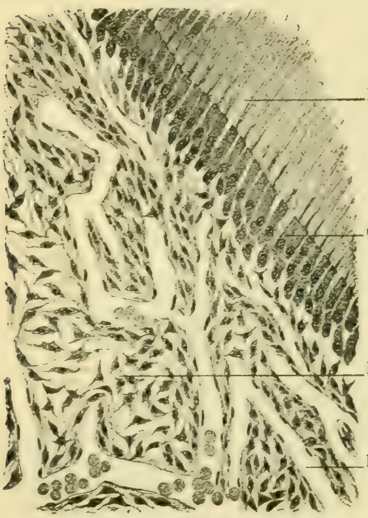
Ground-section of root of dried tooth including adjacent dentine and cementum. × 300.

The Alveolar Periosteum.—The periosteum investing the jaws likewise lines the sockets receiving the roots of the teeth, which are by this means securely held in place. The name *pericementum* is often applied to this special part of the periosteum, which clothes the alveoli on the one hand and covers the cement on the other, thereby fulfilling the double rôle of periosteum and root-membrane. The latter consists of tough bundles of fibrous tissue, elastic tissue being almost wanting, which are prolonged into the penetrating fibres characterizing the cementum on one side and into the fibres of Sharpey of the alveolar wall on the other. The fibrous bundles run almost horizontally in the upper part of the root, but become more oblique towards the apex of the fang. In the latter situation the pericementum loses its dense character and becomes a loose connective tissue through which the blood-vessels and nerves pass to reach the tooth. The less dense portions of the root-membrane between the penetrating bundles of fibrous tissue contain, in addition to the vessels and nerves, irregular groups of epithelial cells which appear as cords or net-works within the connective-tissue stroma. These groups are the remains of the epithelial sheath which surrounded the young tooth during its early development. They have sometimes been described as glands, lymphatics, and other structures, their true nature being unrecognized. At the alveolar margin the pericementum is directly continuous with the tissue composing the gum, the fibrous bundles being so disposed immediately beneath the enamel-border that they form an encircling band of dense fibrous tissue, the *ligamentum circulare dentis* of Kölliker, which aids in maintaining firmer union between the tooth and the alveolar wall.

The Pulp.—The contents of the pulp-cavity is the modified tissue of the mesoblastic dental papilla remaining after the completed formation of the dentine. The major part of the adult pulp consists of a soft, very vascular connective tissue containing few or no elastic elements, but numerous irregularly distributed cells of uncertain form. The general type of the tissue resembles the embryonal, both in the character of the fibrous tissue and of the cells, which are round, oval, or stellate with long processes. The fibrous bundles and the more elongated cells are most regularly disposed around the blood-vessels and nerves, which they invest in delicate fibrous sheaths.

The peripheral zone of the pulp, next the dentine, presents the greatest specialization, since in this situation lie the direct descendants of the dentine-producing cells, the odontoblasts. In this locality the pulp, especially in older teeth, presents three layers. The outer (.04–.08 mm. thick) consists of several rows of large cylindrical elements, of which the most superficial are arranged vertically to the free surface of the pulp, after the manner of an epithelium. These are the *odontoblasts*, now no longer active, about .025 mm. in length and .005 mm. broad, which send out long, delicate processes (the *dentinal fibres*) into the dental tubules externally, and shorter ones towards the pulp-tissue. When very young they probably possess also lateral processes. The deeper cells of the odontoblastic layer are less regularly disposed and less cylindrical in form. The second, or *Weil's layer*, best seen in older teeth, is characterized by absence of cells, the fibrous tissue and the cell-processes forming a clear, cell-free zone which separates the striking layer of odontoblasts from the subjacent third or *intermediate layer*. The latter consists of numerous small round or spindle-cells, closely placed, but irregularly disposed, which gradually blend with the ordinary pulp-tissue.

FIG. 1312.



Section of periphery of pulp-tissue of young tooth. × 175.

The *blood-vessels* supplying the pulp are from three to ten small arteries which soon after entering the pulp-cavity break up into very numerous branches from which a rich capillary net-work is derived. In human teeth the capillaries usually do not invade the layer of odontoblasts, although at times the vascular loops may extend between these cells. The venous radicles form larger veins which follow the course of the arteries. *Lymphatics* have been demonstrated as networks within the pulp.

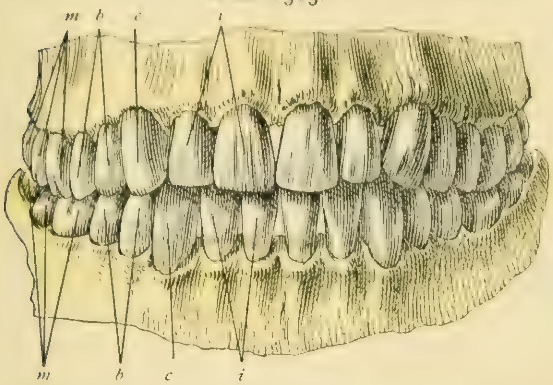
The *nerves* are numerous, each fang receiving a main stem and several additional smaller twigs, which in a general way accompany the blood-vessels in their coarser distribution. On reaching the crown-pulp the larger twigs are replaced by finer branches, which divide into innumerable interwoven fibres. The latter, on reaching the margin of the pulp, form a peripheral plexus beneath the layer of odontoblasts, from which terminal non-medullated fibrillæ are given off. Some of these end beneath the odontoblasts in minute knot-like swellings ; others penetrate the odontoblastic layer to terminate in pointed free endings. There is no trustworthy evidence supporting the view that the nerves directly communicate with the odontoblasts, but they have been traced into the dentinal tubules.

IMPLANTATION AND RELATIONS OF THE TEETH.

The Permanent Teeth.—Each fang is implanted in a socket corresponding to it in shape, so that the pressure is transmitted from the surface of the conical fang throughout, except at the very tip, which has a hole for the vessels and nerves. A corresponding hole in the socket communicates with the dental canals. The human

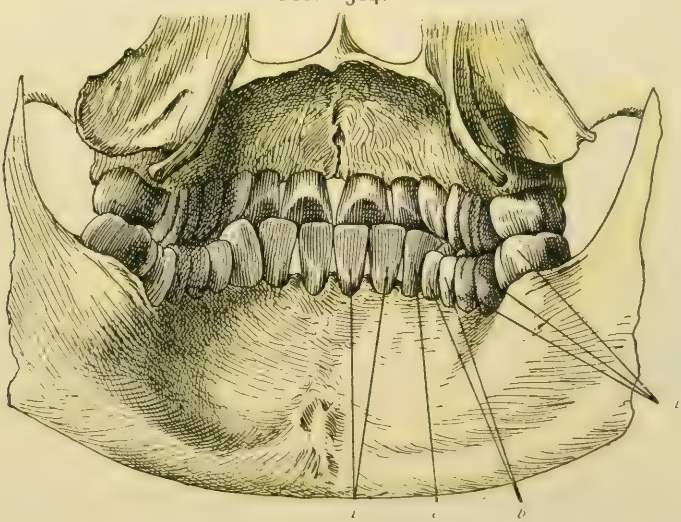
teeth are all in contact with their neighbors, there being no break or *diastema* in the upper jaw between the incisors and canines for the points of the canines of the lower jaw. The canines project very little beyond the line of the free edges. The crowns increase in size from the incisors to the first molars and then decrease. The vertical distance from the gum to the free edge regularly diminishes from the median incisors backward, with the exception of the canines. The lines of the teeth above and below are practically of the same length. When the mouth is closed the superior canines lie to the outer side of the inferior ones, opposite the ends of the lips; thus the median upper incisors impinge on both the lower ones of the same side, and the upper lateral incisors strike both the lower lateral and the canine. In the same way the point of the cusp of the upper first bicuspid rests between the points of both the inferior ones, and that of the second on both the second lower and the first molar. The first upper molar has, perhaps, a quarter of its grinding surface on that of the inferior second molar, but a smaller part of the second upper molar rests on the lower wisdom-tooth. The smaller size of the upper wisdom-tooth brings its posterior border into line with that of the lower. This arrangement causes the opposed crowns to interlock to a certain extent, but not so closely that grinding movements cannot occur between them. The advantage of each tooth coming in contact with two is evident after the loss of a tooth, as the one corresponding to it is not rendered useless. In the upper jaw the incisors have a marked

FIG. 1313.



Dental arches seen from before. Letters in this and subsequent cuts indicate the groups of teeth: *i*, incisors; *c*, canines; *b*, bicuspids; *m*, molars.

FIG. 1314.



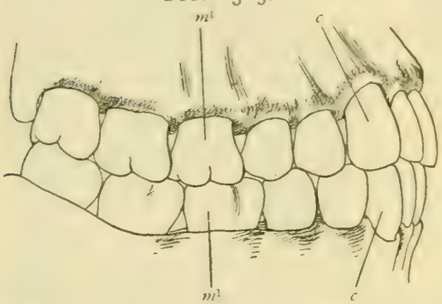
Dental arches seen from behind.

forward inclination, and overlap the lower, concealing nearly a third of their crowns, the mouth being closed. The crowns of the upper bicuspids look pretty nearly downward and those of the molars slant outward. This is very marked in the wisdom-tooth and may be very slight in the first molars. The lower incisors have the front surfaces nearly vertical; the molars have an inward slant, so as to bring their axes into the same line

as those of the upper ones ; hence it follows that the alveolar arches of the upper and lower teeth are in different curves, the latter having a great transverse distance between the necks of the wisdom-teeth.

The right half of the jaw is usually the stronger and the teeth form a smaller curve. It has been pointed out in the section on the motions of the lower jaw that the line between the molars, and probably the bicuspids, is a part of the circumference of a circle the centre of which is near the top of the lachrymal bone ; it may now be added that the line of the cutting edges of the lower incisors is a part of a transverse curve with the convexity upward. There is no corresponding concavity in the line of the edges of the upper incisors, for the lower do not naturally meet them ; but the convexity plays along the lingual surfaces of the upper ones. The position and shape of the superior incisors make their inner surface a part of a vault. A transverse section of this is necessarily a curve with an upward convexity. The wearing of the outer corners of the lateral incisors is evidence of this action. The fact that there is no purely lateral motion, but an oblique one, modifies, without invalidating, this conception.

FIG. 1315.



Dental arches seen from the side, showing relations of upper and lower teeth.

The relations of the roots of the superior teeth to the antrum are very important. The incisors have no relation with it whatever. The long fang of the canine is opposite the wall between the antrum and nose, and separated by diploë from the former. The first bicuspid is usually separated in the same manner. The second is very close to its front wall and may indent the floor. The first and second molars always do this. The wisdom-tooth also indents it at the junction of the floor with the posterior wall. Its relation, owing in part to its varying development, is less certain. Exceptionally the first bicuspid and even the canine may be in contact with the antrum. Thus caries of the roots of any of the molars, but especially of the first and second, sometimes of the second bicuspid and exceptionally of the first, or even of the canine, may lead to inflammation of the antrum. In certain cases pus may pass directly into it from the root.

The Temporary Teeth.—In the first dentition the dental arches differ from the permanent ones in showing a broader curve, more nearly approaching half a circle, symmetrical on both sides, in having the upper incisors less slanting, and the molars of each row more nearly vertical. This implies less difference in curve between the jaws. The line of meeting of the teeth is more horizontal. The crowns increase in size from the incisors backward. In the young child the antrum is but a small pouch, and the roots of the first teeth and the sacs of the second lie in diploëtic tissue. The first permanent molar, as its fangs grow, is nearest the antrum, having extended above it by the end of the second year. In its early stages the first bicuspid is too far forward to have any relation to the antrum, and the second reaches only its extreme anterior border. The second permanent molar is at first behind rather than below it, and the third is still higher. As these descend they swing around the antrum. Thus the roots of only the first permanent molar are in approximately the same relation to the antrum throughout.

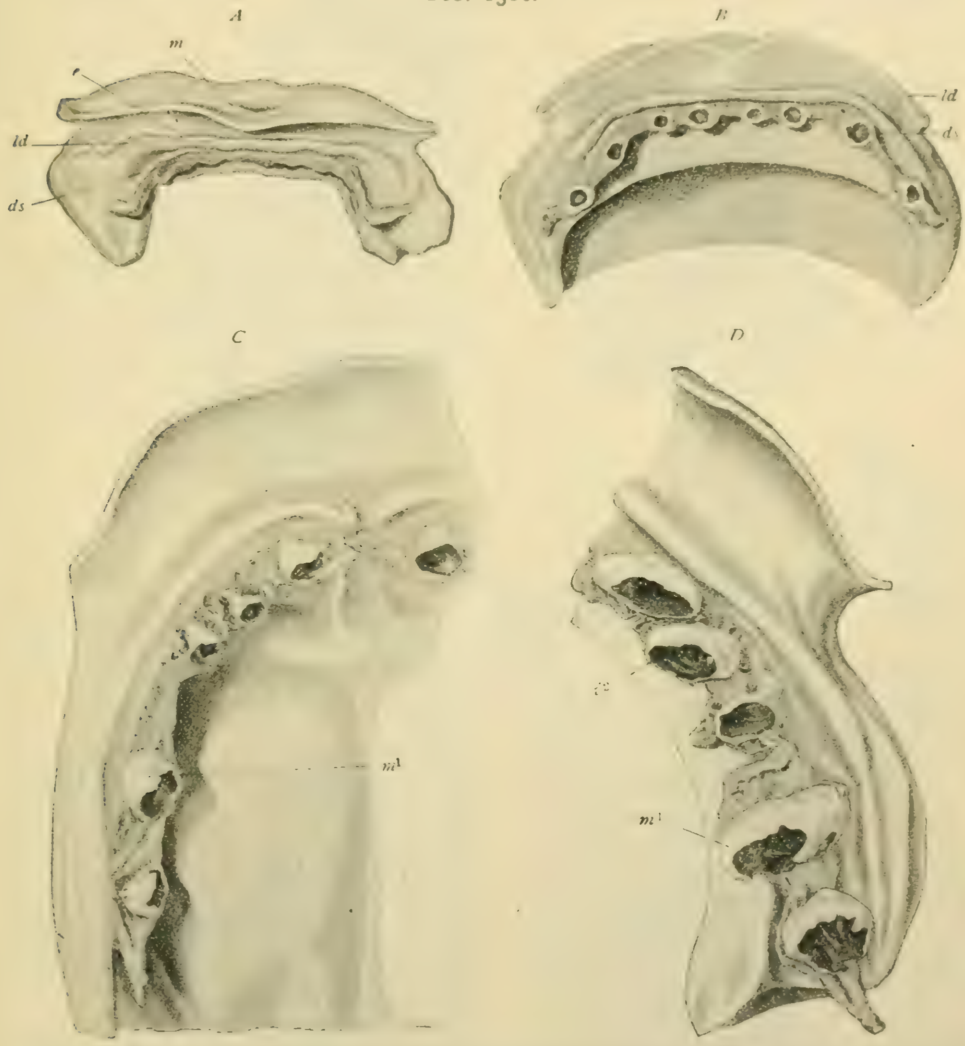
DEVELOPMENT OF THE TEETH.

About the beginning of the seventh week of fœtal life the ectoblastic epithelium presents a thickening along the margins of the oral cavity. The ridge-like epithelial proliferation, or *labio-dental strand*, so formed grows into the surrounding mesoblast and divides into two plates which, while still continuous at the surface, diverge almost at right angles at the deeper plane. The lateral or outer plate is vertical, and corresponds to the plane of separation which soon occurs in the differentiation of the borders of the lips and jaw. The median or inner plate grows more horizontally into the mesoblast, and is the one intimately concerned in the tooth development ; for this

reason it is termed the *dental ledge*. It will be seen that the formerly described primary stage of the dental groove is unfounded, since the furrow that does exist is secondary and not directly related to the formation of the teeth, but to the differentiation of the lips. During the third fœtal month the anlages for the entire set of milk-teeth become evident along the dental bar, coincidently, by the eleventh week, the completion of the *labial furrow* separating the lip from the original epithelial strand with which the dental ledge alone for a time remains attached.

The anlages of the milk-teeth are indicated by club-shaped epithelial outgrowths which grow down from the deeper surface of the dental ledge to form the *enamel-*

FIG. 1316.



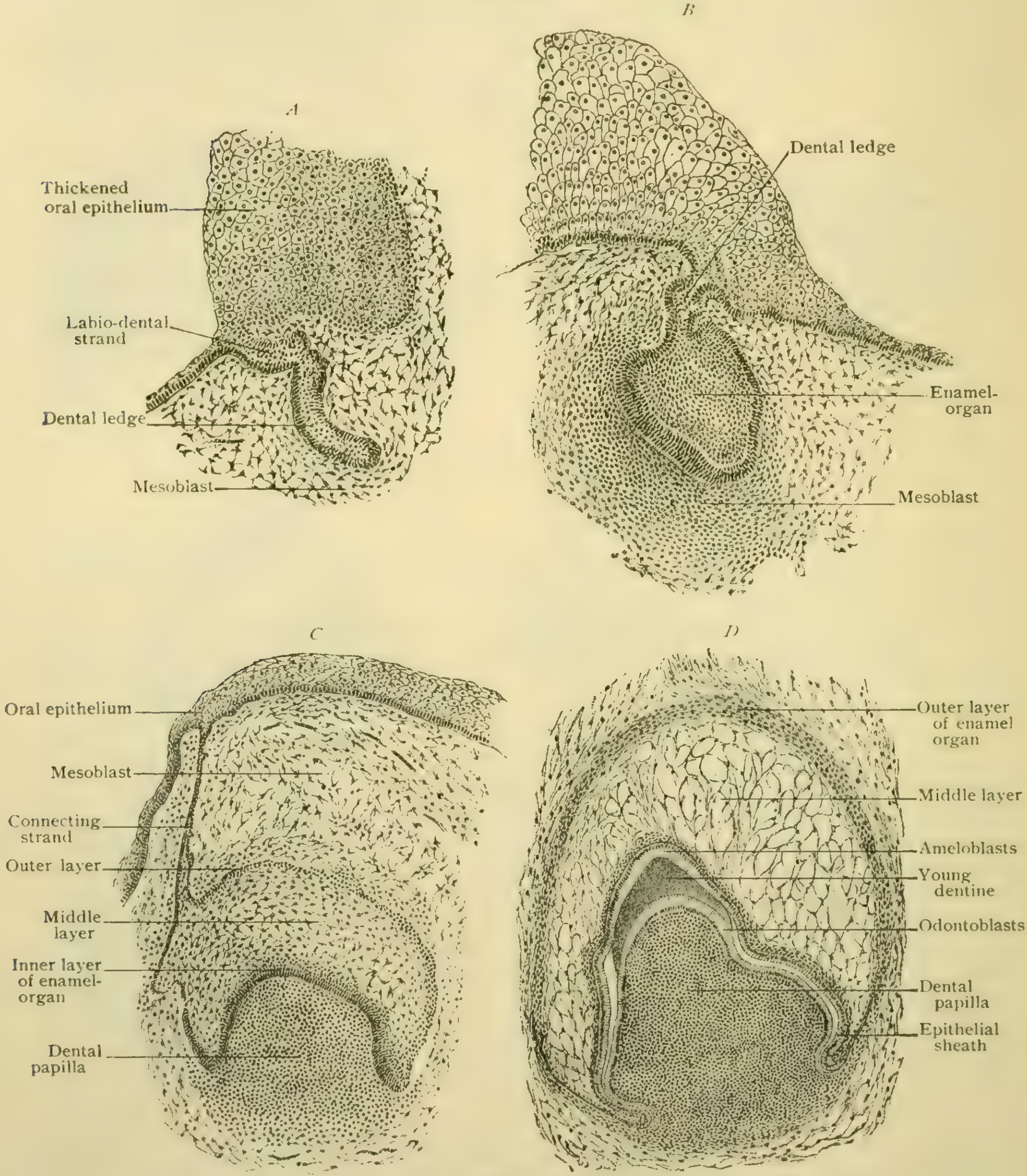
Reconstructions of oral ectoblast of human embryos; only epithelium of lips, mouth, and enamel-organs shown. *A*, embryo of 2.5 cm. length; *m*, oral opening; *e*, labial epithelium; *ld*, reverse of labio-dental groove; *ds*, dental ledge. *B*, embryo of 4 cm.; *la*, projection caused by labio-dental groove; *ds*, dental ledge. *C*, embryo of 11.5 cm., or of about fourteen weeks; m^1, enamel-organ of first molar tooth. *D*, embryo of 18 cm., or of about seventeen weeks; i^2 m^1, enamel-organs of second incisor and of first molar teeth. (*Drawn from Röse's models.*)

organs and to meet, and later cap, the mesoblastic elevations or *dental papillæ*. With the rapid growth and expansion of the extremity of the epithelial plug, a differentiation of the latter into the typical three-layered enamel-organ takes place, the projecting dental papilla apparently invaginating the overlying epithelial structure. At first connected by a broad band of cells, the attachment of the enamel-organ with the

dental ledge becomes more and more attenuated until finally it is broken ; its remains appear for some time as nests or islands of epithelial cells embedded within the young connective tissue of the alveolar border.

The Dental Papilla.—This structure first appears shortly after the beginning expansion of the club-shaped developing enamel-organ as a condensation of the meso-

FIG. 1317.



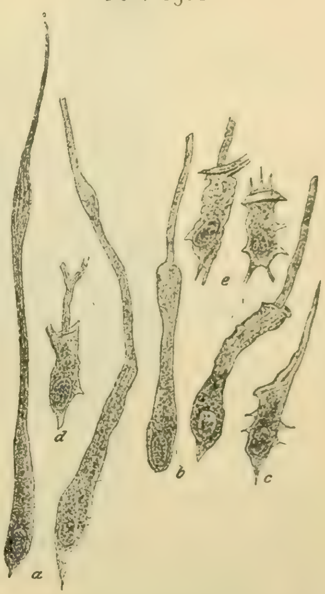
Frontal sections, showing four early stages of tooth-development. *A*, *B*, × 100 ; *C*, *D*, × 60.

blast beneath the epithelial ingrowth. The papilla consists for a time of a close aggregation of small, round, proliferating cells ; with the differentiation of the layers of the enamel-organ, the elements occupying the periphery of the dental papilla become elongated and arranged as a continuous row of cylindrical cells over the apical portion of the papilla beneath the capping enamel-organ. These cylindrical mesoblastic cells are the *odontoblasts*, the active agents in the formation of the dentine.

When engaged in the latter process the cells measure from .035–.050 mm. in length and from .005–.010 mm. in breadth, but over the sides of the papilla they gradually become lower until towards the base they blend with and become indistinguishable from the deeper cells of the mesoblastic elevation. So long as the tooth grows, division proceeds and odontoblasts are differentiated in the vicinity of the last-formed parts of the root; after, however, the odontoblasts are engaged in forming dentine, mitosis is no longer to be observed in these elements.

The **formation of the dentine** is accomplished through the agency of the odontoblasts much in the same manner that the osteoblasts produce the matrix of bone. The earliest trace of the dentine appears as a thin homogeneous stratum, the *membrana præformativa*, overlying the coincidently forming layer of odontoblasts. Although separable by certain reagents as a cuticular structure, the membrane is only a part of the general dentinal ground-substance with which it blends; it is resolvable into collagenous fibrils similar to those of bone-lamellæ. The *dentinal matrix* deposited through the influence of the odontoblasts, is for a time without fibrous structure and uncalcified, the deposition of the lime salts occurring first near the apex of the papilla and next the enamel, a zone of uncalcified matrix around the pulp-cavity marking the youngest dentine. The calcareous material is first deposited in the form of globules, the *dentinal spheres*, the calcification being completed by the subsequent invasion of the interstices between the spherical masses. When for any reason calcification is incomplete these clefts remain lime free, a condition seen in the interglobular spaces already described. The spherical form of the calcareous deposits is indicated by the uneven condition of the inner surface of the dentine in macerated teeth, the wall of the pulp-cavity presenting numerous minute hemispherical projections which correspond to the globular masses of lime salts. The scalloped border and pitted outer surface of the dentine, together with the extension of the dentinal tubules as far as or into the enamel, point to the absorption of the primary dentine constituting the preformed membrane, probably through the influence of the enamel. As emphasized by Ebner,[1] the formation of the fibrillæ of the ground-substance takes place independently of the direct influence of the dentine-cells, since the general disposition of the earliest fibrillæ is at right angles to that of the odontoblasts and their processes. The dentinal matrix differs from that of bone in being the production of a single set of cells, while the osseous tissue is the collective work of different elements, many of which, after contributing their increment, become surrounded by the ground-substance to form the bone-corpuscles within the lacunæ. In human dentine, on the contrary, the odontoblasts are only rarely, under normal conditions, imprisoned within the ground-substance which they have formed. The demands made upon the odontoblasts during their active rôle as dentine producers are met by the nutrition supplied by the rich vascular supply of the dentinal papilla, so that for a time the cells are enabled not only to increase the dentinal matrix, but also to extend their processes, which they send into the tubules of the dentine as the dentinal fibres, without diminution in size. With the completion of dentine production, and the consequent decrease in the area upon which they rest, the odontoblasts become narrower and smaller (Walkhoff); later they exhibit evidences of impaired vitality and degeneration, their dentinal processes likewise growing thinner and less flexible and assuming the characteristics of the fibres of Tomes of the adult tissue. According to Walkhoff, the dentinal fibres suffer in size as the result of their activity in the production of the sheath of the tubules.

FIG. 1318.



Isolated odontoblasts from incisor tooth of new-born child. *a*, *b*, from upper part of crown; *c*, *d*, *e*, from lateral region. × 400. (*Ebner*.)

[1] In Kölliker's Gewebelehre des Menschen, 6te Auf., 1899.

After the entire dentine has been formed, the odontoblasts remain as the peripherally situated pulp-cells, retaining their connection with the dentine by means of the dentinal fibres. The other portions of the dental papilla become converted into the pulp-tissue, which retains the embryonal type throughout life and later receives the larger vascular and nervous trunks.

The Enamel-Organ.—The extremity of the cylinder of ectoblastic epithelium which early marks the position of the future tooth by its ingrowth from the dental ledge soon broadens out and becomes invaginated to form the young enamel-organ overlying the apex of the mesodermic dental papilla. In contrast to the latter, which as the pulp-tissue remains as a permanent structure, the enamel-organ is but embryonal and transient, and later entirely disappears. When fully developed, the enamel-organ consists of three principal parts,—the outer, middle, and inner layers. Since the organ, originally pyriform, is converted into a cap by the invagination of its broader and deeper surface, it follows that the external and internal layers are directly continuous at the margin of the inverted area.

FIG. 1319.

Sagittal section through mandible and surrounding structures of eighteen-weeks fœtus. × 30.

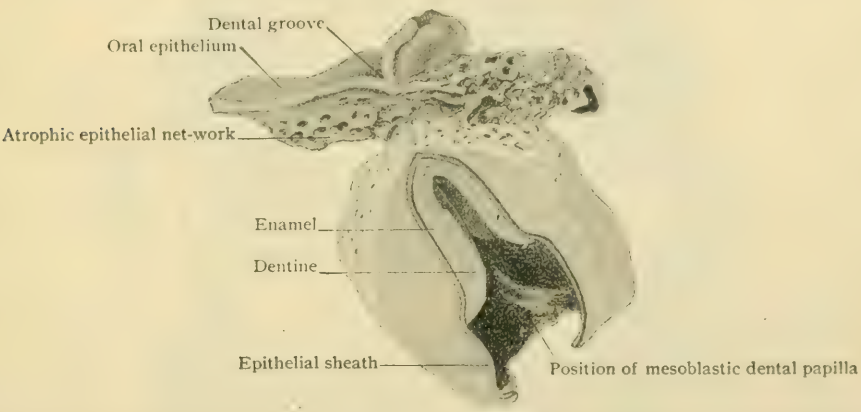
The *outer layer* consists of larger and smaller epithelial cells of flattened form and about .010 mm. average diameter; these cells send numerous processes into the surrounding vascular connective tissue forming the tooth-sac which invests the dental germ, whereby, in conjunction with the vascular tufts, the sac and the enamel-organ are intimately united.

The *middle layer* of the enamel-organ consists apparently of mucoid tissue, since it presents a net-work of stellate cells separated by large clear spaces. Critical examination, however, shows that this tissue consists of epithelial elements which have become modified in consequence of an enormous distention of the intercellular spaces by fluid and a corresponding elongation of the intercellular bridges, the epithelial plates in this manner being reduced to stellate cells connected by long, delicate processes. The inner border of the highly characteristic middle layer forms a transition zone, known as the *intermediate layer*, in which gradations from the modified to the ordinary type of stratified epithelium are seen. The intermediate layer is best marked over the upper part of the crown, at the sides thinning out and entirely dis-

appearing at the margin of the enamel-organ, where the outer and inner layers of the latter are continuous. The modified epithelial tissue of the middle layer, sometimes called the *enamel-pulp*, is greatest in amount just prior to, or during the beginning of, active tooth-formation, about the fifth or sixth fœtal month.

The *inner layer* of the enamel-organ comprises a single row of closely set, tall, cylindrical elements, the *enamel-cells*, *adamantoblasts*, or *ameloblasts*, through the active agency of which the enamel is produced. The ameloblasts are best developed where they cover the apex of the dental papilla, the location of the earliest formed dentine; in this situation the cells measure from .025–.040 mm. in length and from .004–.007 mm. in breadth. They possess an oval nucleus about .010 mm. long, which usually lies close to the outer end of the cell, embedded in cytoplasm exhibiting a reticulum and often minute granules. The ameloblasts are united with one another by a small amount of cement-substance, and are defined from the intermediate layer by a fairly distinct border. Opposite the sides of the dental papilla, corresponding to the limits of the future crown, the ameloblasts gradually diminish in height until they are replaced by low cubical cells which, at the margin of the enamel-organ, are continuous with the epithelium of the outer layer. Preparatory to the formation of the dentine of the tooth-root, this margin grows downward towards the base of the elongating dental papilla, which is thus embraced by the extension of the

FIG. 1320.



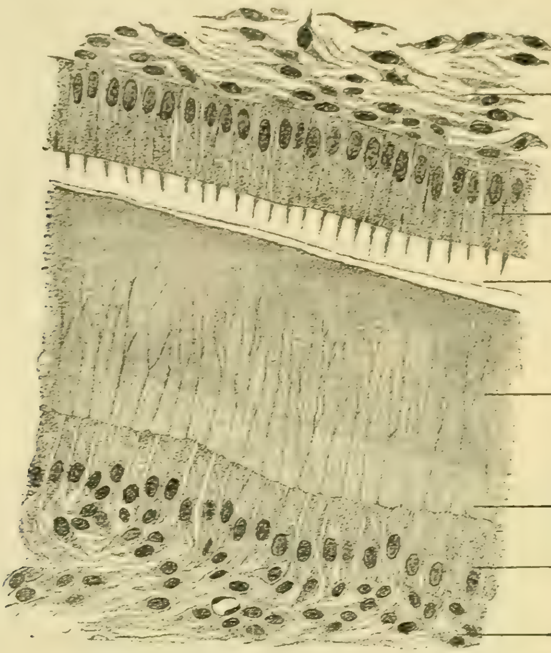
Reconstruction of developing lower incisor tooth from embryo of 30 cm. length, about twenty-four weeks. (*Drawn from Röse's model.*)

enamel-organ. The investment thus formed constitutes the *epithelial sheath* (Fig. 1320), a structure of importance in determining the form of the tooth, since it serves as a mould in which the young dentine is subsequently deposited; there is, however, insufficient evidence to regard the epithelial sheath as an active or necessary factor in the production of the dentine.

The **formation of the enamel,** in contrast to that of the dentine, results from the activity of ectoblastic epithelium, and may be regarded as a cuticular development carried on by the ameloblasts. The earliest stage in the production of enamel is the appearance of a delicate cuticular zone at the inner end of the ameloblast; this fuses with similar structures tipping the adjoining cells to form a continuous homogeneous mass. The latter soon exhibits differentiation into rod-like segments, the *enamel-processes*, or *processes of Tomes*, which are extensions from the ameloblasts and are the anlages of the enamel-prisms, and the interprismatic substance. The latter becomes greatly reduced in amount as the development of the enamel-columns progresses; the major part, becoming incorporated with the processes of Tomes, forms the cortical portion of the enamel-prisms, while the remainder persists as the cement-substance which exists in meagre quantity between the mature prisms. The enamel-processes are for a time uncalcified, but with the more advanced formation of the enamel-prisms the calcareous material, which is deposited as granules and spherules, appears first in the axis of the prism, later invading the periphery (Ebner). The

enamel increases in thickness by the addition of the last-formed increments at the inner ends of the ameloblasts, the same cells sufficing for the deposit of the entire mass. Owing to the expansion of the external surface of the crown, the diameter of

FIG. 1321.



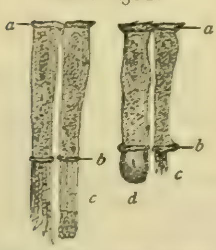
Section of developing tooth through junction of enamel and dentine. × 400.

the enamel-prisms augments towards their outer ends to compensate for the increased area which they must fill, since no additional prisms are formed.

The complex curvature of the enamel-prisms and the oppositely directed ranges of the latter, producing the appearance of Schreger's stripes, result from changes in the position of the enamel-cells incident to the growth of the crown, since the axes of the newly formed prisms correspond with those of the ameloblasts, variations in the direction of which affect the disposition of the enamel-columns.

The earliest formed enamel lies in close apposition with the oldest dentine constituting the membrana præformativa ; the last developed immediately beneath the ameloblasts. The enamel, therefore, is deposited from within outward, or in the reversed direction followed by the growth of the dentine. The oldest strata of both substances lie in contact ; the youngest on the extreme outer and inner surfaces of the tooth.

FIG. 1322.



Isolated ameloblasts from incisor of new-born child. *a*, basal plate; *b*, cuticular border; *c*, processes of Tomes; *d*, homogeneous mass still covering process. × 400. (*Ebner*.)

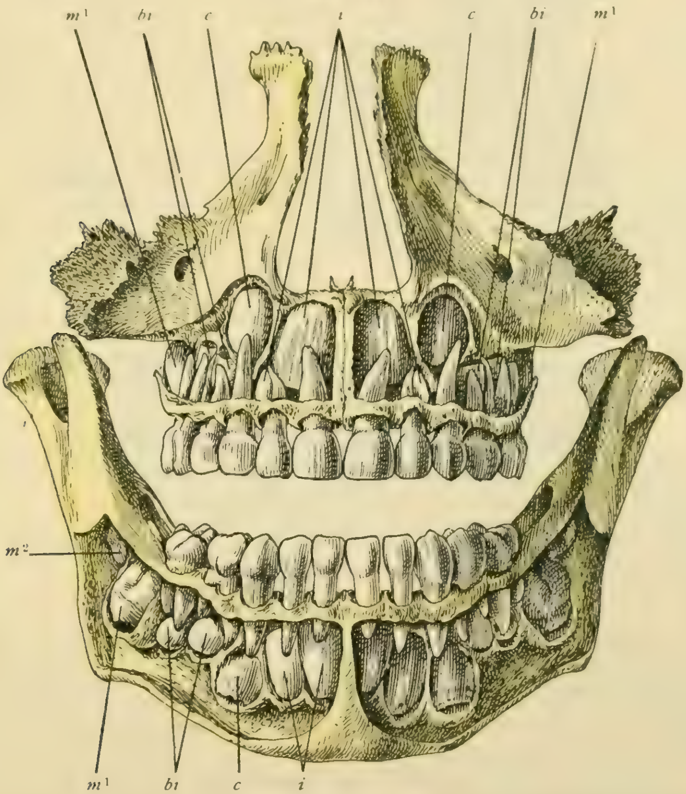
After the requisite amount of enamel has been produced, differentiation into prisms ceases, in consequence of which the last-formed enamel remains as a continuous homogeneous layer investing the free surface of the crown, known as the membrane of Nasmyth.

The Tooth-Sac.—Coincidently with the development of the enamel-organ and the growth of the dental papilla, the surrounding mesoblast undergoes differentiation into a connective-tissue envelope known as the dental or tooth-sac. The latter not only closely invests the enamel-organ, but is intimately related to the base of the dental papilla, with which it is continuous. In contrast to the epithelial enamel-organ, which is entirely without blood-vessels, the

inner part of the tooth-sac is richly provided with capillaries, and therefore is an important source of nutrition to the developing dental germ. The part of the sac opposite the root of the young tooth is at first prevented from coming into direct contact with the dentine by the double layer interposed by the epithelial sheath. This relation is maintained until the development of the cement begins, when the vascular tissue of the dental sac breaks through the epithelial sheath to reach the surface of the dentine, upon which the cementum is deposited by the mesoblast. In consequence of this invasion, the epithelial sheath is disrupted into small groups or nests of cells which persist for a long time as epithelial islands within the fibrous tissue of the alveolar periosteum into which the dental sac is later converted.

The **formation of the cementum** takes place through the agency of the mesoblastic tissue in a manner almost identical with the development of subperiosteal

Fig. 1323.



Jaws of child of six years, showing all temporary teeth in place with permanent teeth in various stages of development.

bone, the active cement-producing cells, or *cementoblasts*, corresponding to the osteoblasts which deposit the osseous matrix upon the osteogenetic fibres of the periosteum. A conspicuous feature of cementum is the unusual number of transversely disposed bundles of fibrillæ, or Sharpey's fibres, among which many are imperfectly calcified. The cementum appears first in the vicinity of the neck of the tooth, and progresses towards the apex of the root as the dentine of the fang is deposited. After the tooth is fully formed, the layer of cement continues to grow until thickest at the apex, which it completely invests, with the exception of the canal leading to the entrance of the pulp-cavity. The cement being deposited directly upon the homogeneous layer constituting the external surface of the dentine, the firm connection between the two portions of the teeth is one of adhesion rather than of union. Later secondary changes may exceptionally bring the canaliculi of the cement into communication with the terminations of the dentinal tubules. During the changes incident to the

completed tooth-development the tissue of the dental sac becomes denser, the part opposite the root persisting as the pericementum which intimately connects the cementum with the alveolar wall, while the more superficial part blends with the tissue forming the gum.

The **development of the permanent teeth** is early provided for by the differentiation of the anlages of the secondary dental germs during the growth of the first. This provision includes the thickening and outgrowth of the dental bar to form the enamel-organ of second dentition, and later the appearance of a new dental papilla beneath the epithelial cap. The enamel-organ for the first permanent molar appears about the seventeenth week of fœtal life, followed soon by the corresponding dental papilla. The germs of the permanent incisors and canines, including the papillæ, are formed about the twenty-fourth week ; those for the first bicuspids are seen at about the twenty-ninth week, and those for the second bicuspids about one month later. The interval between the formation of the enamel-organ and the associated dental papilla increases in the case of the last two permanent molars. While the enamel-germ of the second molar appears about four months after birth and the corresponding papilla two months later, the enamel-organ for the third molar, or wisdom-tooth, which is visible about the third year, precedes its papilla by almost two years.

The First and Second Dentition and Subsequent Changes.—At birth the jaws contain the twenty crowns of the milk-teeth, the still separate cusps of the first permanent molars, one of which has begun to calcify, and the uncalcified rudiments of the permanent incisors and canines behind and above the corresponding milk-teeth of the upper jaw, behind and below those of the lower. At birth the bony plate above the alveoli of the upper jaw is separated by a little diploë from the floor of the orbit. The milk-teeth come through the gum in five groups at what are called dental periods, separated by intervals of rest. The grouping is more regular than the time of eruption. The teeth of the lower jaw have a tendency to precede their fellows of the upper.

TABLE OF ERUPTION OF MILK-TEETH.[1]

	Dental Periods.	Groups of Teeth.
I.	Six to eight months.	Two middle lower incisors.
II.	Eight to ten months.	Four upper incisors.
III.	Twelve to fourteen months.	Two lateral lower incisors and four first molars.
IV.	Eighteen to twenty months.	Four canines.
V.	Twenty-eight to thirty-two months.	Four second molars.

The interval between the first and second periods is practically nothing. It is very common to have the first two groups appear together. After this every interval is longer than the preceding one. In the matter of time no part of development is more irregular than that of the teeth. The first incisors occasionally appear early in the fifth month and sometimes not till the tenth, or even later. The first dentition is sometimes complete at or shortly after the close of the second year. The roots are not fully formed when the crowns pierce the gums. The first set of teeth is in its most perfect condition between four and six years.

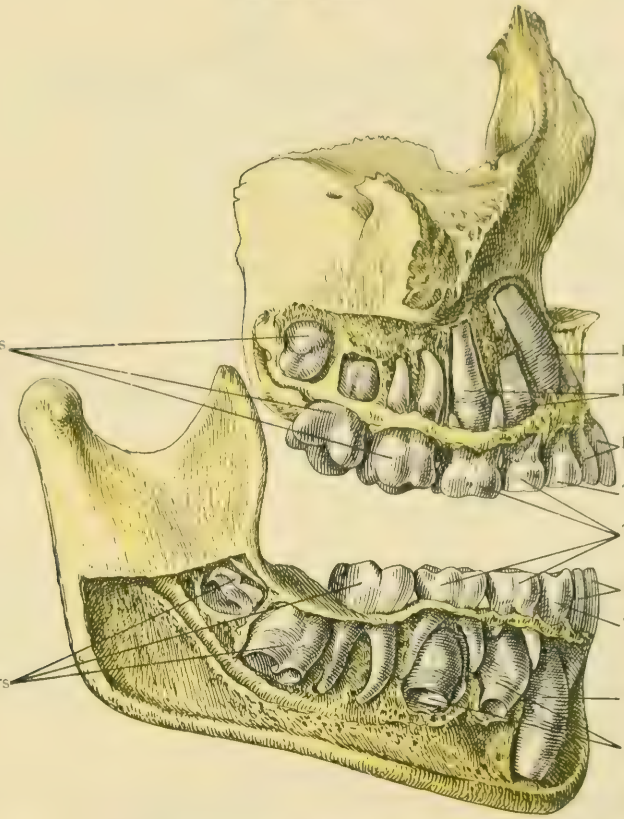
Calcification of the second set begins in the first molar before birth, in the incisors and canines at about six months, the bicuspids and the second upper molar in the third year, the second lower molar at about six, and the wisdom-tooth at about twelve.

The first permanent molars come into line with the milk-teeth, piercing the gums before any of the latter are lost. Before eruption the upper first molars lie nearer the median line and farther forward than the lower. The roots of the incisors are absorbed and the crowns fall out to make way for their successors. The molars do the same for the bicuspids which grow between their roots. The permanent superior canines are developed above the interval between the lateral permanent incisors and the first bicuspid, which are almost in contact. An expansion of the jaw is necessary for them to come into place. The inferior ones have more room. Both are somewhat external to their predecessors. The second upper molar comes down from above and behind,

[1] From Rotch's Pediatrics.

and so does the wisdom-tooth much later. The inferior second molar is formed almost in the angle between the body and ramus. The inferior wisdom-tooth, before it cuts the gum, faces forward, inward, and slightly upward. To the table from

FIG. 1324.



Jaws of child of ten years, showing partially erupted permanent teeth with temporary canines and molars still in place.

Rotch we add one from Livy,[1] who made observations on several thousand children of English and Irish operatives.

TABLE OF ERUPTION OF PERMANENT TEETH.[2]

Years.	Groups.	Years.	Groups.
6	Four first molars.	10	Four second bicuspids.
7	Four middle incisors.	11	Four canines.
8	Four lateral incisors.	12	Four second molars.
9	Four first bicuspids.	17 to 25	Four wisdom-teeth.

TABLES SHOWING TIME OF ERUPTION OF PERMANENT TEETH.[3]

BOYS.

Ages.	9	10	11	12	13	14	15	16	Total.
Lateral incisors	2	42	9	4	1	1	..	..	59
First bicuspids	1	76	12	1	..	..	..	..	90
Second bicuspids	..	59	36	5	..	1	..	..	101
Canines	..	18	28	25	8	..	..	..	79
Second molars	..	5	42	67	275	184	78	12	663

[1] British Medical Journal, 1885. [2] From Rotch. [3] From Livy.

Girls.

Ages.	9	10	11	12	13	14	15	16	Total.
Lateral incisors		24	8	4	. .	. .	. .	. .	36
First bicuspids		56	13	2	1	1	.	.	73
Second bicuspids		51	16	2	2	. .	. .	.	71
Canines		30	34	12	5	. .	1	. .	82
Second molars		5	44	80	288	249	66	14	746

(It seems possible from the method employed that, especially in the case of the second molars, the tables may err on the side of overstating the age.) Livy's researches show that in the first dentition the first molars, incisors, and canines come through first in the lower jaw. In most cases the bicuspids come first in the upper. The second molars come first in the lower jaw, unless their appearance is delayed, in which case the order is uncertain. The date of the appearance of the second molar can be only an approximate guide to the age. When it is present the child is unlikely to be under twelve. The change in the shape of the jaw—namely, the lengthening necessary for a longer row of larger teeth, as well as the widening required to make room for the canines—begins in the course of the second dentition and continues after its close, as the second molar does not at once assume its permanent position in regular line with the rest. It was pointed out in the section on the growth of the face that the greatest activity of growth takes place at the pauses of dentition. The roots of the permanent teeth are by no means fully developed at their eruption. With their perfection the sockets are formed around them by the harmonious moulding of the parts involved.

Homologies.—There are two chief evolutionary theories of the origin of the mammalian teeth: one, the concrescence theory, is that they are formed by the growing together of originally separate cones, the primitive reptilian teeth. This view is supported by Röse[1] and Kükenthal,[2] at least for the bicuspids and molars. Cope,[3] whom Osborn[4] has followed, advanced the differentiation theory, according to which the many cusps of the molars have arisen as outgrowths from a primitive cone. This is based on comparative anatomy and paleontology. According to this, there was first the *cone*, in the upper jaw called the *protocone* and in the lower the *protoconid*. Two secondary cusps next appeared respectively before and behind it: the *paracone* and *metacone* of the upper teeth and the *paraconid* and *metaconid* of the lower. The next change is for these to move to the labial side in the upper jaw and to the lingual in the lower. Thus the primitive cone and these two secondary ones form the points of a triangle with the base outward in the upper jaw and inward in the lower. A prolongation, the *talon* or *heel*, is next developed on the posterior end of the tooth, and rises into a single cusp, the *hypocone* in the upper jaw and the *hypoconid* in the lower. The last, however, has two secondary cusps spring from it, the *entoconid* and the *hypoconid*. According to this theory, the *paraconid* of the lower teeth has disappeared in the human molars owing to want of room consequent on the development of the talon of the upper teeth. The following table shows the homologies of the cusps of the human molars according to Osborn.

Upper Molars.

Anterior lingual	Protocone.	Forming the triangle.
Anterior buccal	Paracone.	
Posterior buccal	Metacone.	
Posterior lingual	Hypocone.	The talon.

Lower Molars.

Anterior buccal	Protoconid.	Remnant of triangle.
Anterior lingual	Metaconid.	
Posterior buccal	Hypoconid.	The talon.
Posterior lingual	Entoconid.	
Posterior	Hypoconulid.	

Röse has advanced, in support of his theory of concrescence, that calcification begins separately for each cusp. Osborn points out that Röse has shown that they ossify very nearly in the order of their alleged evolution. Schwalbe[5] professes himself unable to decide on the relative merits of the two theories.

Variations.—Variations of the cusps and of the fangs have been described with the teeth. Those of number affect chiefly the incisors and molars. An additional incisor may occur on one or both sides in either dentition, not very rarely in the upper jaw, but extremely so in the lower, the condition in the latter being more stable. Extra upper incisors are often more or less displaced to the rear and implanted obliquely. They are particularly common in cases of cleft palate; not impossibly the presence of additional teeth predisposes to the non-union of the

[1] Anatom. Anzeiger, Bd. vii., 1892.
[2] Jenaische Zeitschrift, Bd. xxviii., 1893.
[3] Journal of Morphology, 1888, 1889.
[4] American Naturalist, 1888, and International Dental Journal, 1895.
[5] Anatom. Anzeiger, Bd. ix., 1894.

premaxillary and the maxillary bones, or to the non-union of two parts of the former, supposing that two such parts really exist. The extra incisor may apparently appear on the median side of the first, between the first and second, or between the latter and the canine. To account for this Rosenberg[1] asserts that the typical number is five, as in the opossum, of which the second and fourth are the two persistent ones, and that either the first, third, or fifth may occasionally present itself. Th. Kolliker[2] records a case of right cleft palate in which, besides the four regular incisors, three were found between the cleft and the right canine. As cases of excess of incisors are much more common than of deficiency, the disappearance of the upper lateral one does not seem imminent; still, there are signs of degeneration. The crown is less square than that of the central, it is occasionally pointed, often unusually small, sometimes not reaching the line of the other crowns. It may be absent, and then a series of cases can be made ranging from those in which the remaining incisor is separated both from its fellow of the other side and from the canine beside it by large gaps to those in which the teeth are regular and continuous. Very rarely one of the lower incisors is wanting, and, according to Rosenberg, either may fail.

A fourth molar is very uncommon; but not at all rarely the wisdom-tooth is late in coming through the gum, and occasionally it never does. It seems sometimes to be wanting and often is rudimentary. It has been seen represented by three detached cusps, an apparent confirmation of Röse's views of the homology of the teeth.

The entire dental series may be unusually large or small. In the former case the face is prognathous, probably as a result of the increase of space required for the teeth. The upper central incisors are occasionally very large without increase in size of the other teeth. The same is true of the molars; in which case the number of cusps is generally greater, but the converse does not occur when the molars are unusually small.[3]

The points of the canines may project beyond the line of the other teeth and the molars may increase in size from the first to the third.

Teeth are sometimes remarkably displaced. The superior canines, owing to their high origin in the second dentition, are particularly subject to it. They may appear on the front of the jaw, in the antrum, the nose, or the back of the mouth. The molars, and especially the wisdom-teeth, are also erratic.

THE GUMS.

This term is used rather vaguely to indicate the mucous membrane and submucous tissue covering the alveolar processes and closely attached to the necks of the teeth. Whether the neck is entirely surrounded by it varies in different individuals as the teeth are not in all equally close; as a rule, owing to the ordinary expansion of the crown from the neck, at least a little of the gum is found between the teeth. It is some 3 mm. thick, dense, firmly fastened to the bone, and is neither very vascular nor very sensitive.

In structure the gums resemble other parts of the oral mucous membrane, consisting of the epithelium and the connective-tissue layer. The latter, directly continuous with the periosteum of the alveolar border and the pericementum, is composed of closely fitted bundles of fibrous tissue and beset with numerous papillæ. On young teeth the epithelium is prolonged for from .5–1 mm. over the enamel and often for a short additional distance over the cement, ending in an abrupt margin. In the immediate vicinity of the tooth the papillæ sometimes exhibit infiltrations of lymphoid cells. The gums are without glands. The structures sometimes described as such, as the "glands of Serres," consist of nests of epithelial cells derived from the remains of the atrophic embryonal epithelial sheath (page 1563).

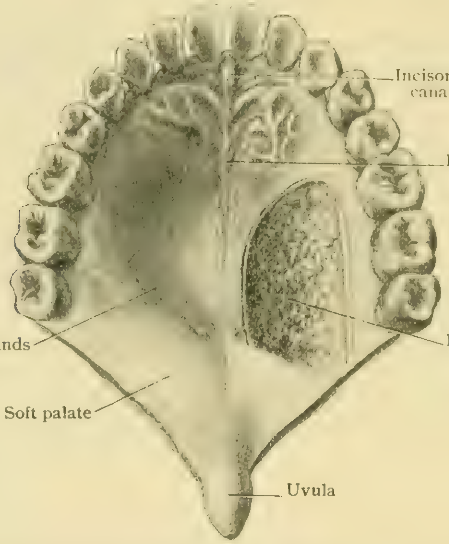
THE PALATE.

The Hard Palate.—The shape and proportions of the hard palate have been discussed with the bones (page 228), so we have here to do only with its mucous covering. This is very firmly fastened to the rough surface of the bones by dense connective tissue which is particularly thick at the sides, doing much to fill up the angle between the roof and the alveolar process. On either side near the front, extending onto the inner surface of the alveolar processes, is a series of raised ridges (Fig. 1325), in the main transverse, although slightly convex anteriorly, the analogues of the *palatal rugæ* of most mammals. They never extend behind the first molar tooth, are numerous and prominent in childhood, but much reduced in middle age, and occasionally wholly lost.

[1] Morphol. Jahrbuch, Bd. xxii., 1895.
[2] Nova Acte des Leopold. Carol. Akad. der Naturforscher, Bd. xliii., 1882.
[3] Magitot: Traité des Anomalies du Système Dentaire, 1887.

Just behind the incisors, at or before the incisor canal, there is a small raised *pad* or fold of mucous membrane, on either side of which the orifice of the *incisor canal* is often found. When pervious, it is very minute, admitting merely a bristle. Behind this the palate presents a median *raphe* of paler color than the rest, which may

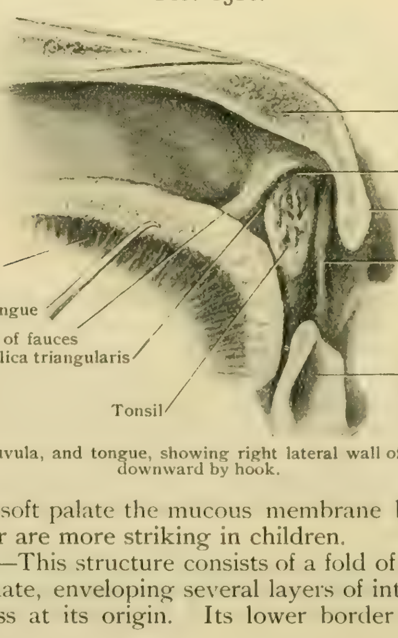
FIG. 1325.



Superior dental arch and palate; palatal rugæ occupy anterior part. Soft palate partially cut away.

run to the root of the uvula or may stop short of it, being often deflected to the left. A little behind the pad this line may be interrupted by a pale oval elevation or more often a depression. The membrane of the roof of the mouth is nowhere bright red; that of the hard palate, however, is paler than the rest. There are no glands in the oval white space, but there is a continuous layer on either side of it. The orifices of the glands are easily seen with a lens, sometimes with the naked eye. A little in

FIG. 1326.



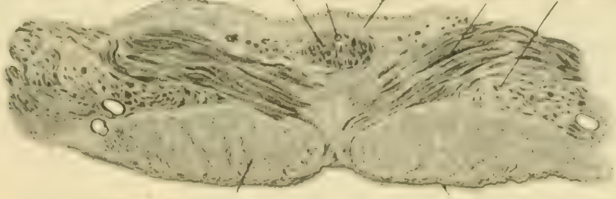
Sagittal section through palate, uvula, and tongue, showing right lateral wall of fauces; tongue has been pulled downward by hook.

front of the origin of the soft palate the mucous membrane becomes deeper colored. These differences in color are more striking in children.

The Soft Palate.—This structure consists of a fold of mucous membrane, continuous with the hard palate, enveloping several layers of interlacing muscular fibres, at least 1 cm. in thickness at its origin. Its lower border is the edge of the fold.

This is concave on each side, and presents a median elongation, the *uvula*, which varies from a short prominence to a cord 2 cm. in length. Thus the palate has a lower surface looking downward and forward and an upper one looking upward and backward. When the mouth is closed the palate and uvula rest against the tongue; when open they hang free, but the muscles inside can modify their shape and position. Median sections show the tip of the uvula often reaching within half

FIG. 1327.

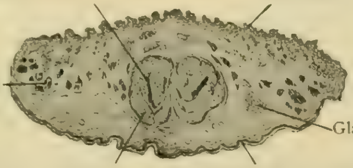


Transverse section of soft palate near its anterior attachment. × 4.

an inch of the tip of the epiglottis. Possibly muscular relaxation allows it to descend somewhat farther than in life, but it is certain that no very great elongation is necessary for it to touch that organ and give rise to great discomfort. The soft palate can be raised so as to touch the back of the pharynx and close all communication between the nose and the mouth. Two folds, *the pillars of the fauces*, each the reflection of the mucous membrane over a muscular bundle, start from the palate on either side. The *anterior pillar*, enclosing the *palato-glossus* muscle, arises from the front of the palate near the uvula, some distance anterior to the edge, and, curving downward, runs to the tongue at the junction of the middle and posterior thirds, separating the mouth from the pharynx and forming the posterior border of the *sublingual space.* The *posterior pillar* starts from the lower border of the palate on either side of the uvula, covering the *palato-pharyngeus*, and runs down the throat to the superior cornu of the thyroid cartilage, the lower part being indistinct. Some of the muscular fibres within it go to the upper border of the thyroid cartilage in front of the horn, but the fold is not often found so low, except in frozen sections, in which it appears at the sides of the back of the pharynx.

A deep triangular recess on either side, between the anterior and posterior pillars, contains the tonsil. This region is often vaguely described as the *isthmus of the fauces*, one being left in doubt whether it belongs to the pharynx or to the mouth. In the preceding pages the pharynx is described as beginning at the anterior pillar. The reasons for this division are developmental, morphological, and physiological. The part of the tongue anterior to this fold is of mandibular (buccal) origin, while the part behind it comes from the pharynx. The surface of the former is supplied by the mandibular nerve, the third division of the fifth, and the latter by the glosso-pharyngeal. The mucous membrane of the posterior third does not bear papillæ (except the circumvallate papillæ near the junction of the two regions), but is rich in adenoid tissue and glands, differing in both respects from the part in front of it. The arrangement of the transverse fibres of the glosso-palati muscles in the substance of the tongue suggests a sphincter at the entrance of the pharynx. Finally, in deglutition it is in passing this line that the bolus ceases to be under the control of the will.

FIG. 1328.

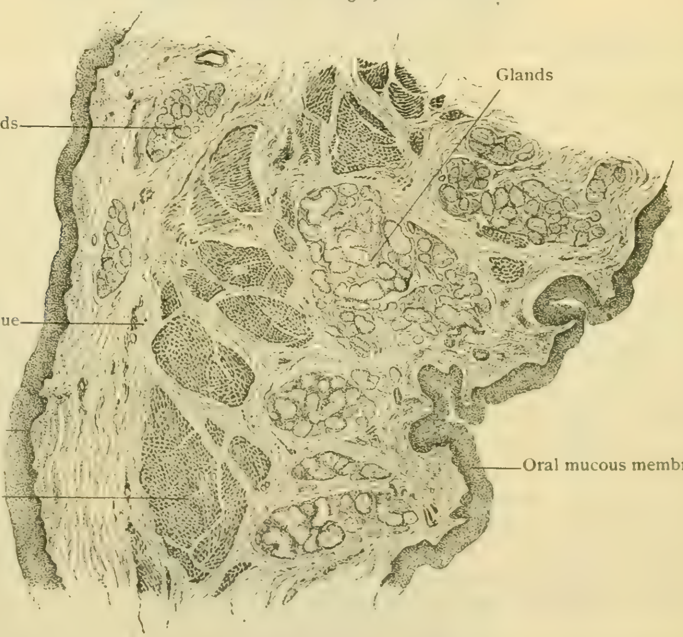


Transverse section of soft palate near base of uvula. × 4.

The following layers compose the soft palate from above downward : (1) The pharyngeal mucous membrane. (2) A fibro-muscular layer. The fibrous portion is the expansion of the tendons of the tensor palati muscles. It is strong and tense near the hard palate, gradually dwindles lower down, and joins the pharyngeal aponeurosis at the sides. Below this is the complex of the muscles. (3) A glandular layer opening into the mouth. This is some 5 mm. thick at its origin and practically continuous throughout most of the palate. It is interrupted at the median line near the hard palate by a septum of muscular and fibrous tissue, is wanting near the free edge of the palate a little on either side of the root of the uvula, and is continued down the uvula as a cylindrical string of glands nearly to the tip, through and about which run the fibres of the azygos uvulæ muscle. Irregular glandular collections are found near the latter, especially at the base of the uvula. (4) A lower layer of mucous membrane.

The mucous membrane of the soft palate is red on the pharyngeal and pale on the buccal surface ; on both sides it presents papillæ, those on the upper surface

FIG. 1329.



Sagitto-lateral section of soft palate. × 15.

especially being near the base. The most common form, slender and elongated, is scattered over the entire buccal surface and the front of the uvula (Rüdinger). Thicker short papillæ are also found near the beginning of the pharyngeal surface. Small adenoid collections occur on the upper surface, as well as small glands situated in the depth of the mucous membrane. The orifices of the chief glandular layer pierce the inferior palatal surface.

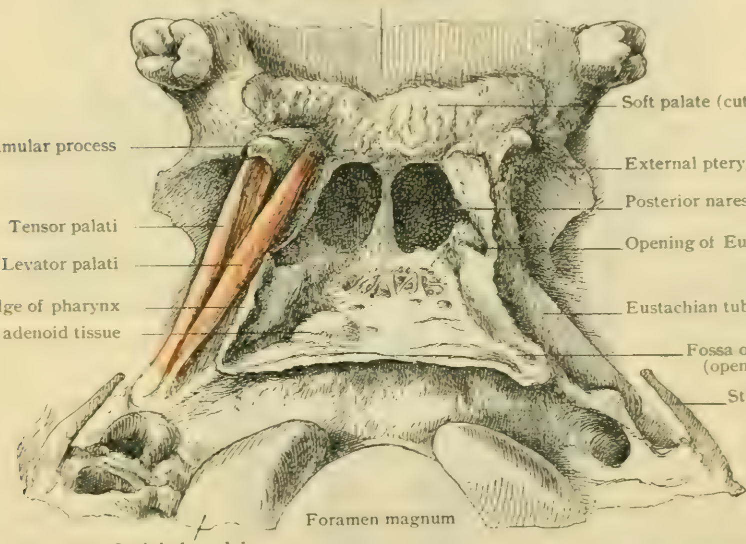
The Muscles of the Soft Palate.—Some of the muscles arise in the soft palate ; others run into it. Isolation of the individual sets of fibres is not always possible.

The **tensor palati** (*dilatator tubæ*) (Fig. 1330) arises from the scaphoid fossa at the root of the internal pterygoid plate, from the spine of the sphenoid, and from the outer membranous part of the Eustachian tube. It descends vertically along the internal pterygoid plate as a round, red, and distinct muscle, which becomes tendinous as it turns inward under the hamular process at right angles to its previous course, after which it broadens into the fibrous expansion in the soft palate already described, above the other muscles. A bursa lies between the tendon and the hamular process.

The **levator palati** (Fig. 1330) arises from the base of the skull at the apex of the petrous portion of the temporal bone and from the cartilaginous part of the Eustachian tube beside it. At first thick, it passes downward, forward, and inward with the tube, and, leaving it, expands into a layer which spreads out through the soft palate. Some of the anterior fibres from the tube go to the back of the hard palate, constituting the *salpingo-palatinus*, while others descend in the lateral wall of the pharynx, covered by mucous membrane, beneath the salpingo-pharyngeal fold. The great body of the fibres crosses the middle line in the front part of the soft palate. Most of them descend in the opposite side. Some seem to form loops with an upward concavity with fibres from the fellow-muscle. Near the hard palate this decussation completely divides the glandular layer (Fig. 1327).

The **azygos uvulæ** (Fig. 1331), although probably a double muscle originally, soon (even at birth) becomes practically a single one. Arising from the tendinous fibres of the tensor palati just behind the posterior nasal spine, it soon becomes muscular and increases in size. Its course is downward into the uvula, but on reaching the base it is already broken up into separate bundles which pass about and through

FIG. 1330.



Inferior surface of skull with upper part of opened pharynx and palatal muscles attached; viewed from behind.

the glandular core of the uvula. The belly of the muscle lies near the dorsal surface, between the fibrous expansion of the tensor palati and the levator palati, which decussates on its oral surface.

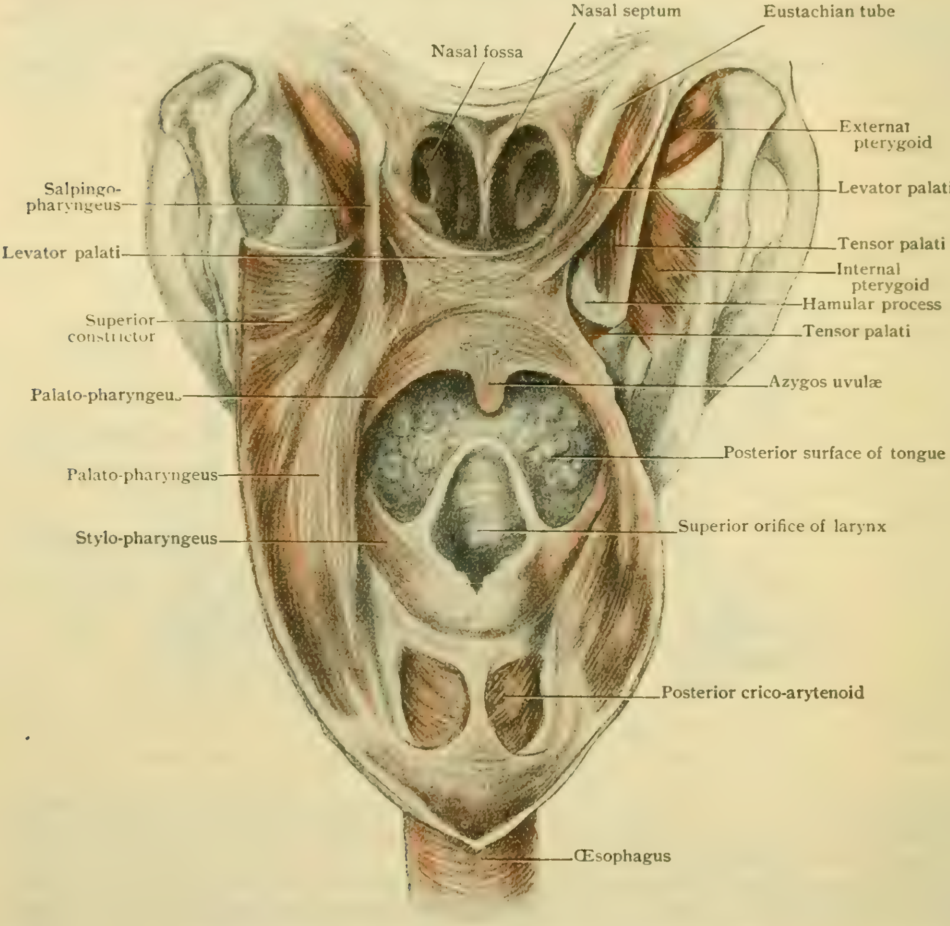
The **palato-pharyngeus** (Fig. 1331) has a complicated origin in more than one layer from the border of the hard palate, from the lower surface of the aponeurosis, and perhaps from fibres of the levator palati. Certain fibres, either arising in the middle line or coming from the other side, pass downward and outward over the azygos uvulæ; others lie beneath the glandular layer. Some of the fibres seem to continue the course of the salpingo-pharyngeus of the opposite side, without being directly continuous. The muscle passes down near the edge of the soft palate and then in the posterior pillar into the side of the pharynx, where it mingles with the stylo-pharyngeus. A part is inserted into the upper border of the thyroid cartilage, and sometimes into the superior horn. It also expands, together with the stylo-pharyngeus, into a thin layer just beneath the mucous membrane of the back of the pharynx, which meets its fellow in the median line where it is inserted into the pharyngeal aponeurosis. Its lower limit is a curved line with the concavity looking upward and outward, behind the larynx (Fig. 1361). (This part

of the muscle must be dissected from behind, after removing the constrictors of the pharynx.)

The **palato-glossus** (Fig. 1339) is a small bundle arising from near the middle line of the oral side of the lower part of the soft palate, forming by its projection the anterior pillar of the fauces, in which it runs to the tongue, where it joins the transverse fibres. The pair of muscles act as a sphincter tending to close the passage from the mouth to the pharynx. A thin expansion from this muscle passes over the tonsil.

Vessels.—The *arteries* of the palate (both hard and soft) come chiefly from the descending palatine, which, emerging from the posterior palatine canal, runs forward along the inner side of the base of the alveolar process. It sends a few branches

FIG. 1331.



Muscles of palate and pharynx, seen from behind ; pharynx laid open.

inward and backward to the front of the soft palate, which is supplied on the side by a branch either from the facial or from the ascending pharyngeal. It is to be noted that no vessel is likely to interfere with the division of the tensor palati at the inner side of the hamular process.

The *veins* of the hard palate follow in the main the arteries. Those of the upper side of the soft palate join the plexus of the zygomatic fossa. The larger ones of the under side connect with the veins of the tonsil and the root of the tongue.

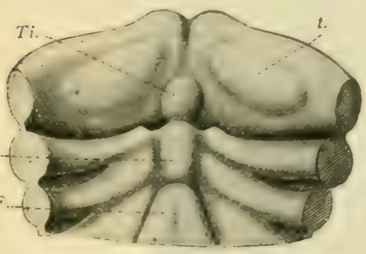
The *lymphatics* of the hard palate and of the under side of the soft palate form a rich plexus. Those on the upper side of the latter are small. The chief current is to the deep glands of the neck.

Nerves.—The tensor palati is supplied by the mandibular division of the fifth pair, the other muscles by the pharyngeal plexus. The mucous membrane of the hard palate is supplied by the anterior palatine nerve and terminal branches of the naso-palatine. That of the soft palate is supplied by the other palatine nerves and by branches from the glosso-pharyngeal.

THE TONGUE.

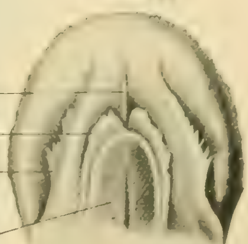
The tongue is a median muscular organ attached to the floor of the mouth, the symphysis of the jaw, and the body and both horns of the hyoid, covered with mucous membrane, which when the mouth is closed it practically fills (Fig. 1339). The *root* is the attached portion, extending from the hyoid to the symphysis, composed of the genio-glossi and the hyo-glossi muscles. The *tip* is the free anterior end, flat both above and below when extended, and surrounded by mucous membrane. Behind this the tongue is a solid mass. The *dorsum* in its anterior two-thirds is convex from side to side, and rests against the hard and soft palates; the posterior third, nearly vertical, looks backward, forming the front wall of the pharynx when the mouth is closed. There is a median groove in the upper part of this posterior third, continued for a little distance onto the top, in which the uvula rests. This hind portion is so broad that the edges of the tongue reach quite to the sides

FIG. 1332



Floor of the mouth and pharynx of an embryo of 7.5 mm. (From a reconstruction.) *cop.*, copula; *F.*, furcula; *t.*, anlage of the body of the tongue; *Ti.*, tuberculum impar; *I–III*, branchial arches.

FIG. 1333.



Under surface of tongue of new-born child. (*Gegenbaur.*)

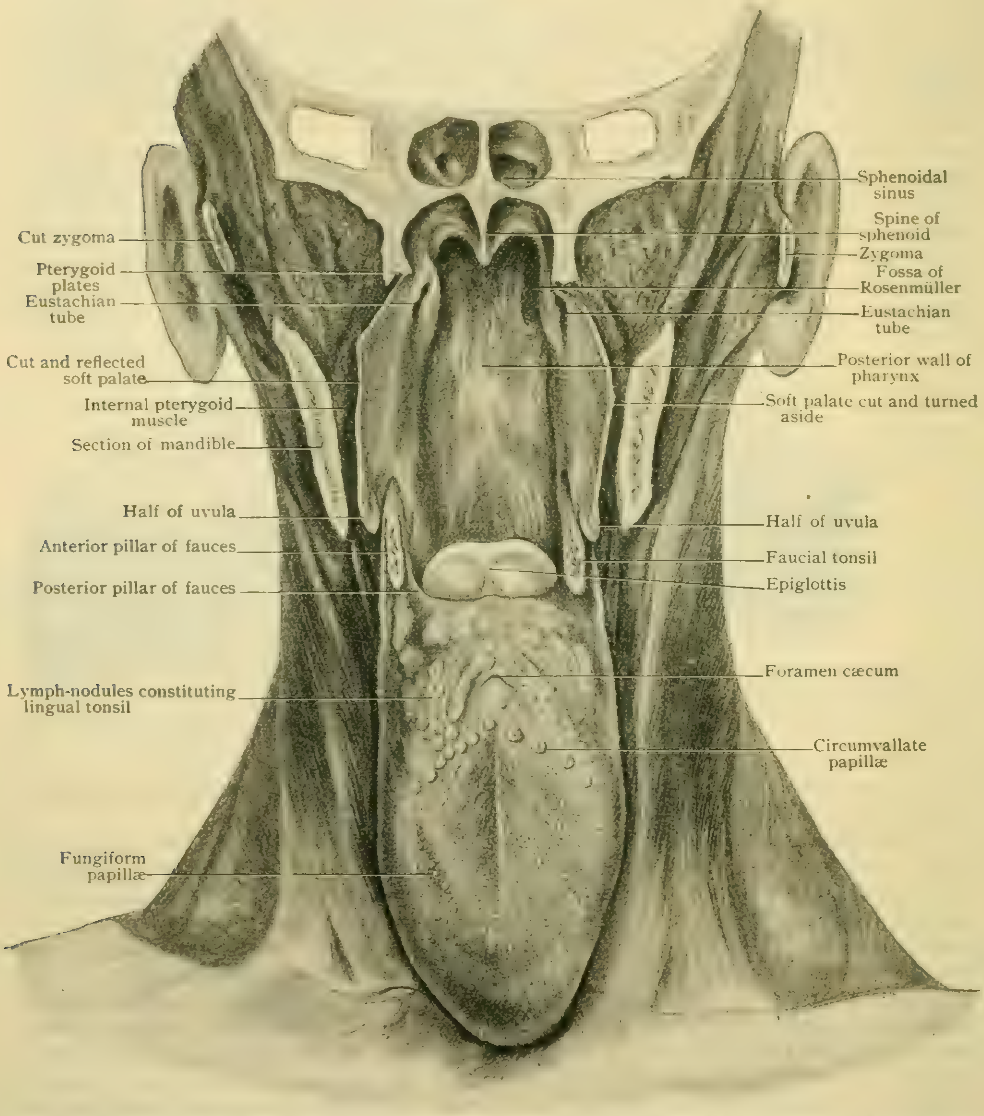
of the pharynx. In the anterior two-thirds the edges of the tongue are prominent, overhanging the sides.

Development shows that the tongue has a double origin. The body arises from a paired anlage near the midline in the anterior part of the mouth, while the root develops from a median elevation, the *copula*, and the adjoining portions of the second visceral arches. The *tuberculum impar* of His plays probably only a subordinate rôle. The *thyro-glossal duct* comes to the surface at the junction of these two parts, which, in the infant, are still separated by the *sulcus terminalis*.

The **mucous membrane** of the lateral and inferior surface is thin and smooth with small papillæ at the tip. In the middle it forms a fold, the *frenum*, running from near the tip to the floor of the mouth. In infancy this is occasionally so short as to restrain the tip of the tongue from the motions necessary for nursing. Often it is hardly visible. The *plica fimbriata* and the *plica sublingualis* are two folds on either side of the front part of the under surface, of which the former with ragged edges is the outer, the longer, and the larger. Both are distinct in the infant and (especially the latter) lost or poorly marked later. The plicæ fimbriatæ bound a triangular space which Gegenbaur considers a rudiment of the under-tongue of some mammals. The mucous membrane of the dorsum is divisible into two wholly different regions: the one comprising the anterior two-thirds, the other the posterior vertical third. The line of separation, or *sulcus terminalis*, is, however, not transverse, but, starting at the side from the anterior pillar of the fauces, runs backward and inward to meet its fellow. This is not usually visible in the adult; but its place is

easily recognized, as just before it is a V-shaped arrangement of circumvallate papillæ, the median apex being at or near a small depression, the *foramen cæcum*, which marks the termination of the fœtal duct through the tongue from the thyroid. In the adult this may be a short tunnel or a depression, into which the ducts of several glands open. According to Münch,[1] it is always behind the hindmost circumvallate

FIG. 1334.



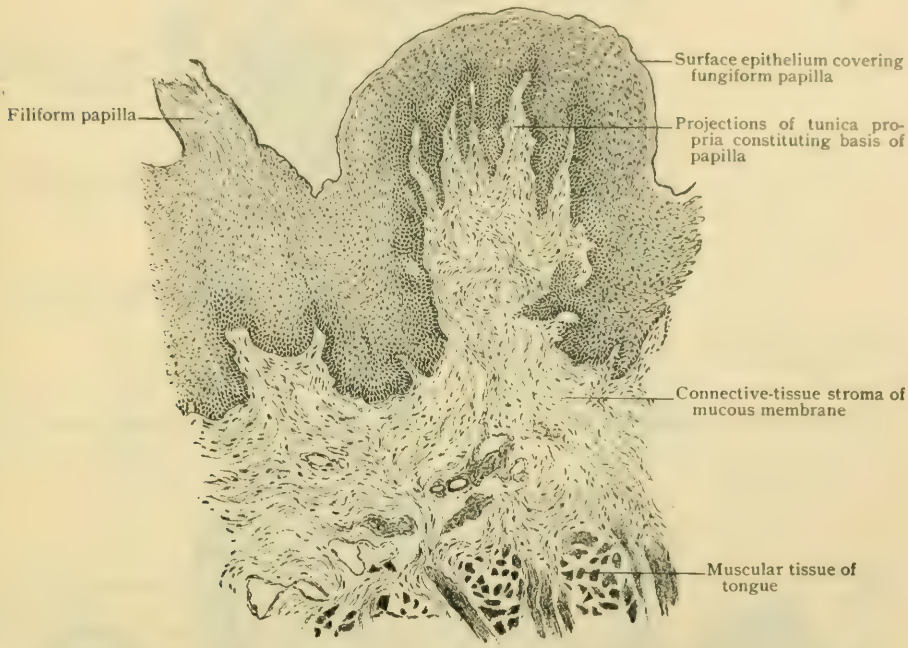
Anterior portion of head has been removed by frontal section passing through plane of posterior nares; the soft palate cut in mid-line and turned aside, exposing posterior wall of pharynx; tongue drawn forward and downward.

papilla. The mucous membrane covering the dorsum of the tongue is closely beset with elevations, or *papillæ*, of which there are three varieties, the filiform, fungiform, and circumvallate. In general they consist of a core of connective-tissue stroma covered with stratified squamous epithelium; the projection formed by the connective tissue bears minute secondary papillæ, which, however, do not model the free sur-

[1] Morpholog. Arbeiten, Bd. vi., 1896.

face of the mucous membrane. The anterior two-thirds of this surface are rough with *fungiform* and *filiform papillæ;* the former, less numerous, appear as red points chiefly near the edges, while the filiform are everywhere, but arranged in parallel rows continuing forward the lines of the circumvallate papillæ. At the edges of the tongue, just in front of the end of the anterior pillar of the fauces, close inspection, especially with a lens, will generally show a small series of minute transverse parallel ridges, corresponding to the *papillæ foliatæ* of rodents in a rudimentary condition. The *papillæ circumvallatæ* are fungoid papillæ surrounded by a depression bounded externally by a low annular wall. The usual number of these papillæ is from nine to ten, ranging from six to sixteen (Münch). The sides of the V in which they are disposed are not very symmetrical. Usually there is at least one median papilla behind the apex, and very rarely one or two before it. The circumvallate papillæ are of especial interest as being the most important seat of the gustatory end-

FIG. 1335.



Section of lingual mucous membrane, showing filiform and fungiform papillæ. × 75.

organs, or *taste-buds*, which lie embedded within the epithelium lining the groove encircling the central elevation. A detailed description of the taste-buds is given with the organs of special sense (page 1433).

The surface of the vertical posterior third of the tongue is smooth, in the sense that there are no papillæ nor roughnesses, but it is studded with masses of lymphoid tissue, sometimes called the *lingual tonsil* (Fig. 1334), which make numerous elevations on its surface. The mucous membrane of the back of the tongue is continued in a thinner layer onto the front of the epiglottis. It presents the *median glosso-epiglottic fold*, containing fibro-elastic tissue and muscular fibres of the genio-glossi, which separate two little depressions, the *glosso-epiglottic fossæ.* These may be without any definite lateral boundary, or may be embraced by the small *lateral glosso-epiglottic folds*, the internal borders of which are concave. The mucous membrane is firmly attached to the subjacent muscles in the anterior two-thirds of the tongue, but less firmly behind.

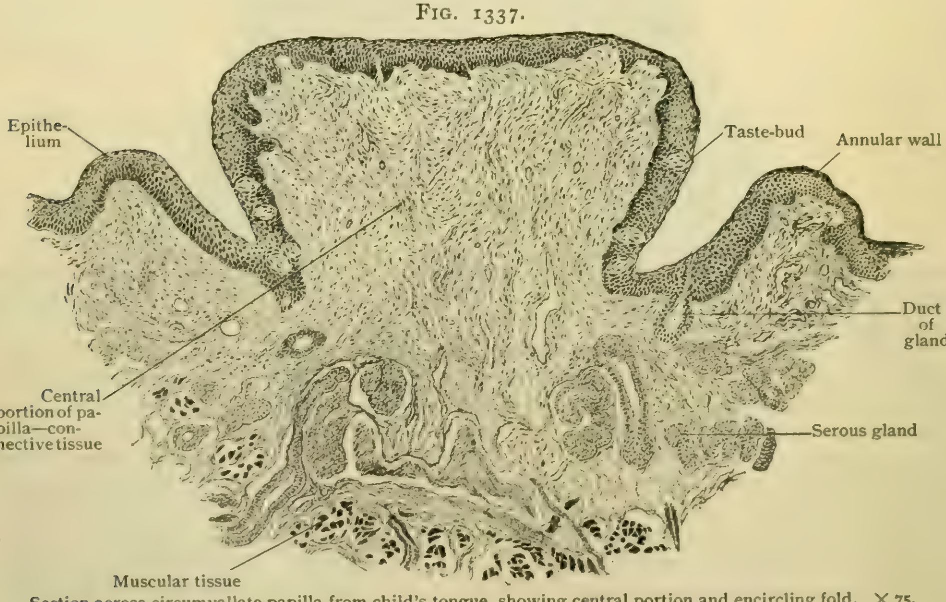
Glands of the Tongue.—The lingual glands include both serous and mucous varieties, which are distributed as three groups: (1) serous glands, (2) posterior mucous glands and (3) anterior mucous glands.

The tubo-alveolar glands surrounding the circumvallate and the foliate papillæ are the only ones of a purely serous type; their thin, watery secretion is no doubt an important medium in conveying sapid substances to the taste-buds situated in this

FIG. 1336.

Injected mucous membrane and subjacent areolar and muscular tissue from upper surface of tongue. × 60.

FIG. 1337.



Section across circumvallate papilla from child's tongue, showing central portion and encircling fold. × 75.

vicinity. The glands encircling the circumvallate papillæ constitute an annular group some 4 mm. wide and about twice as deep. Those about the papillæ foliata form an elongated group, about 3.5 mm. in width, which extends from 8–15 mm. in front of

the base of the palato-glossal fold. Anteriorly towards the dorsum the serous glands remain isolated; posteriorly they come into contact with the mucous glands, so that alveoli of both varieties may be included within a single microscopical field (Fig. 1287).

The posterior third of the dorsum, from the circumvallate papillæ backward, possesses a rich, almost continuous layer of mucous glands, 5 mm. or more in thickness, which lie beneath the mucous membrane and mingle with the lymphoid tissue. Since the alveoli lie among the muscles at some depth, the excretory ducts often attain a length of from 10–15 mm., and open on the free surface in close association with the lymph-follicles.

The anterior mucous glands (Fig. 1352) are disposed principally as two elongated groups, *glandulæ linguales anteriores*, or *glands of Nuhn*, or *of Blandin* (from 15–20 mm. in length, 7–9 mm. in width, and somewhat less in thickness), which lie on either side of the mid-line, near the tip of the tongue, among the muscular bundles. They meet in front, but diverge behind, where they may be continued backward by additional collections of mucous glands along the edges of the tongue. The ducts—five or six in number—open on the folds occupying the under surface of the tongue near the frenulum.

FIG. 1338.

Section from posterior third of child's tongue, showing lymph-nodes constituting a part of lingual tonsil. × 30.

Muscles of the Tongue.—These include two groups, the *extrinsic* and the *intrinsic* muscles. The former pass from the skull or hyoid bone to the tongue; the latter comprise the particular muscles both arising and ending within the organ. Their general arrangement is as follows. Under the mucous membrane is a dense sheath of longitudinal fibres, surrounding the others completely near the apex, and farther back wanting at the middle of the under surface where the fibres of the genio-glossi and hyo-glossi enter the organ. This outer layer is the *cortex*. The inner part is divided into two by a vertical median *septum* of areolar tissue, which is quite dense in its upper part. It is sickle-shaped, with the point in front and not reaching the apex. The inner portion, or *medulla*, is composed of transverse muscle-fibres interposed between layers of those called vertical, which in fact present many degrees of obliquity.

The **extrinsic muscles** are the *genio-glossus*, the *hyo-glossus*, the *stylo-glossus*, and the *palato-glossus*, to which may be added, from its position, the *genio-hyoid*. All of these are in pairs and symmetrical.

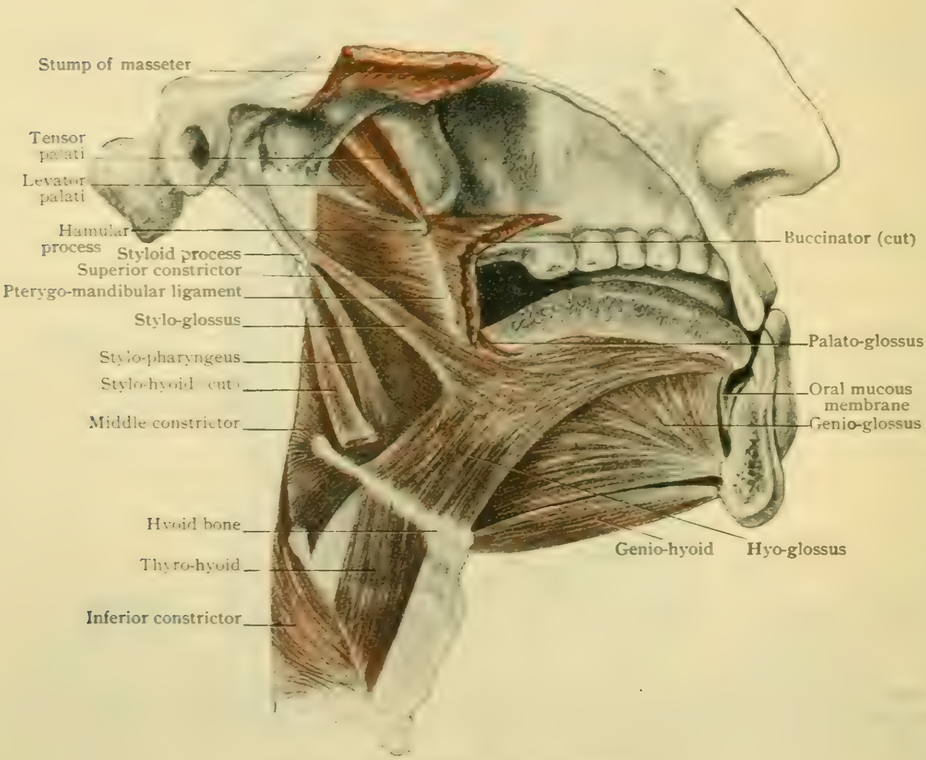
The **genio-hyoid** (Fig. 1339) is a collection of fleshy fibres extending close to the median line, from the inferior genial tubercle to the anterior surface of the body of the hyoid bone. It is a thick band, four-sided on transverse section, with rounded angles, and expands laterally on approaching its insertion. A layer of areolar tissue separates it from its fellow.

Nerve.—The nerve-supply is from the hypoglossal, but probably consists of fibres derived from the cervical nerves.

Action.—To draw the hyoid forward and upward; or, when fixed below, to depress the mandible.

The **genio-glossus** (Fig. 1339) arises just above the preceding by short tendinous fibres from the superior genial tubercle. Its inferior fibres run horizontally backward to the base of the tongue, passing over the hyoid bone to the base of the epiglottis; the fibres above these, inserted successively into the mucous membrane of

FIG. 1339.



Pharyngeal and extrinsic lingual muscles

the dorsum of the tongue near the middle line, are at first oblique, then vertical, and finally concave anteriorly as they approach the apex, so that the muscle is fan-shaped when seen from the side. Each muscle is separated from its fellow by the median septum.

Nerve.—The hypoglossal.

Action.—The complex action of this muscle includes retraction of the tongue by the anterior fibres, drawing forward and protrusion by the posterior fibres, and depression, with increased concavity, of the dorsum by its middle part.

The **hyo-glossus** (Fig. 1339), external to the preceding, from which it is separated by areolar tissue, arises from the side of the body of the hyoid, the whole of the greater horn, and the lesser horn. The last portion, rather distinct from the rest, is described sometimes separately as the **chondro-glossus.** The whole muscle, applied to the side of the tongue, forms a layer of fibres directed upward and for-

ward ; towards the front its fibres are almost longitudinal. The fibres from the lesser horn run on the dorsum beneath the mucous membrane, forming a part of the superficial longitudinal system.

Nerve.—The hypoglossal.

Action.—To depress the sides of the tongue, thereby increasing the transverse convexity of the dorsum ; the muscle also retracts the protruded tongue.

The **stylo-glossus** (Fig. 1339) arises from the tip of the styloid process and from the beginning of the stylo-maxillary ligament. It is a small ribbon like muscle with an anterior and a posterior surface, but as it descends it twists so as to lie along the outer side of the tongue, which it reaches in the region of the circumvallate papillæ. On joining the tongue the fibres divide into an upper and a lower bundle, both of which are chiefly longitudinal, although some fibres blend with the transverse series. It is soon lost in the sheath of longitudinal fibres.

Nerve.—The hypoglossal.

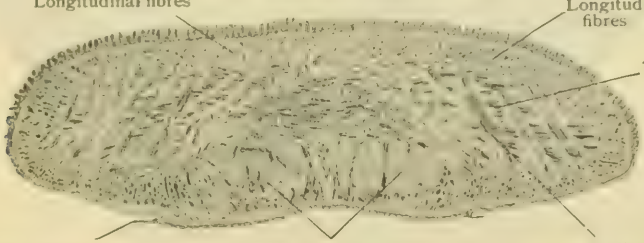
Action.—To retract the tongue and to elevate the sides, thus aiding in producing transverse concavity of the dorsum.

The **palato-glossus** (Fig. 1339) arises from the anterior or buccal aspect of the palate, and descends within the fold forming the anterior pillar of the fauces to the tongue, where it joins the transverse fibres, passing between the two parts of the stylo-glossus.

Nerve.—From the pharyngeal plexus, the motor fibres coming probably from the spinal accessory nerve.

Action.—To elevate the tongue, to depress the soft palate, and, with its fellow by approximating the anterior pillars, to close the fauces.

FIG. 1340.



Transverse section of tongue of child, near tip. × 3.

The **intrinsic muscles** are the *lingualis*, the *transversus*, and the *perpendicularis* (Fig. 1340).

The **lingualis,** sometimes divided into a superior and an inferior, comprises the greater number of the longitudinal fibres,—all, in fact, that do not come from the extrinsic muscles. The thickness of this layer is some 5 mm.

The **transversus** furnishes nearly all the transverse fibres, the most important extrinsic contribution being from the palato-glossus. It arises from the septum and runs outward to the mucous membrane ; as it approaches the cortex the fibres break up into bundles, among which pass groups of the fibres of the lingualis. The transversus is arranged in a series of horizontal layers, between which pass layers of the vertical set. Thus a horizontal section has the effect of a series of transverse fibres like the bars of a gridiron with the cut ends of the vertical fibres between them and the longitudinal fibres of the lingualis at either side. Near the apex fibres of this system run directly from the mucous membrane of one side to that of the other.

The **perpendicularis** is the name given to the few vertical fibres that do not come from the extrinsic muscles. They occur chiefly at the tip and sides, passing from the lower to the upper mucous membrane.

Nerve.—All the intrinsic muscles are supplied by the hypoglossal.

Action.—The tongue is protruded chiefly by the action of the posterior fibres of the genio-glossus, drawing the posterior part of the tongue forward, assisted, perhaps, by the contraction of the transversus. It is withdrawn by its own weight. The

longitudinal system, the various parts of which can act separately, turns the tip in any direction. The stylo-glossus and palato-glossus raise the posterior portion, particularly at the edges, but the latter probably acts more on the palate than on the tongue.

Vessels.—The principal *arteries* supplying the tongue are branches of the lingual, elsewhere described (page 735). Although there may be a trifling anastomosis at the tip between the vessels of the opposite sides, there is no communication sufficient to re-establish the circulation at once, so that ligation of either artery will render that half of the tongue bloodless for an operation. The *veins* consist of four sets on each side, communicating freely with one another. They are (1) the dorsal veins forming a submucous plexus on the back of the tongue above the larynx and joining those of the tonsil and pharynx, (2) two veins accompanying the artery and sometimes forming a plexus about it, (3) two with the lingual nerve, (4) two with the hypoglossal nerve. Of these latter, the one below the nerve is the larger and is the ranine vein, running on the under surface of the tongue on either side of the frenum. The *lymphatics* present a rich net-work on the anterior two-thirds of the dorsum. The multitude of spaces throughout the organ communicate with lym-

FIG. 1341.

Transverse section of tongue of child, through middle third. × 3.

phatics. Some from the median part empty into the suprahyoid glands, but most go to the submaxillary and to the deep cervical glands.

Nerves.—The *motor* fibres are supplied by the hypoglossal, aided probably by the facial through the chorda tympani. Those of *common sensation* are from the lingual branch of the fifth for the anterior two-thirds and from the glosso-pharyngeal for the remainder, excepting the region just in front of the epiglottis, which is supplied by the superior laryngeal from the vagus. The glosso-pharyngeal area somewhat overlaps the posterior third, as it supplies the circumvallate and foliate papillæ. The chief fibres of *special sense* are derived from the glosso-pharyngeal, their principal distribution being to the taste-buds on the circumvallate papillæ. Regarding the source of the taste-fibres to the anterior parts of the tongue opinions still differ. According to many anatomists, these fibres reach their destination through the chorda tympani, since the latter nerve is supposed to receive taste-fibres from the ninth by way of the pars intermedia of Wrisberg, which accompanies the facial. According to Zander,[1] Dixon,[2] Spiller,[3] and others, however, the view attributing fibres of special sense for the anterior part of the tongue partly to the fifth nerve is correct.

Growth and Changes.—At birth the tongue is remarkable chiefly for its want of depth, as shown in a median section, which depends on the undeveloped condition of the jaws. This is gradually corrected coincidently with the growth of the face.

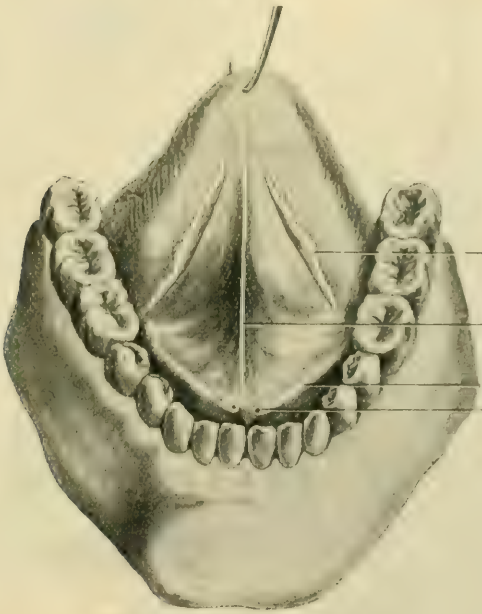
[1] Anatomischer Anzeiger, Bd. xiv., 1897.
[2] Edinburgh Medical Journal, 1897.
[3] University of Pennsylvania Medical Bulletin, March, 1903.

The circumvallate papillæ[1] are imperfectly developed for some time after birth, so much so that it is not easy to recognize them. The foliate papillæ are also relatively undeveloped. On the other hand, the fungiform papillæ are proportionately both larger and more numerous than in the adult. The development of the adenoid tissue at the back of the tongue occurs during the last two months of fœtal life. In places the connective tissue surrounding the ducts of the mucous glands becomes infiltrated with leucocytes and is transformed into lymphoid tissue (Stöhr).

THE SUBLINGUAL SPACE.

This space is between the lower jaw and the tongue, above the mylo-hyoid, and bounded behind by the fold of the anterior pillar of the fauces passing to the tongue. It is lined with thin, smooth mucous membrane reflected from the mandible to the tongue and attached lightly to the parts beneath. With the mouth closed, this space is filled by the tongue. It is best examined in the living subject when the tip of the tongue is against the upper incisors. A fold of mucous membrane, the *frenum*,

FIG. 1342.



Sublingual space, tongue pulled up.

if well developed, passes in the middle line from the tongue to end over the floor of the mouth. Close to its termination on either side is a smooth elevation caused by the sublingual gland, which in the present position is drawn upward under the tongue. A varying number of gland-ducts perforate the mucous membrane with orifices hardly visible to the naked eye. Internal to these swellings at the lower end of the frenum is a small enlargement on each side of the median line, so closely blended, however, as to seem but one; these elevations, the *carunculæ salivares*, mark the point at which the duct of the submaxillary gland opens on each side. This duct runs along the floor of the sublingual space between the mylo-hyoid muscle and the mucous membrane, a small part of the gland usually accompanying the duct a short distance over the muscle, forming a prominence, the *sublingual ridge* (plica sublingualis). A constant group of glands is found in the mucous membrane below the incisors.[2]

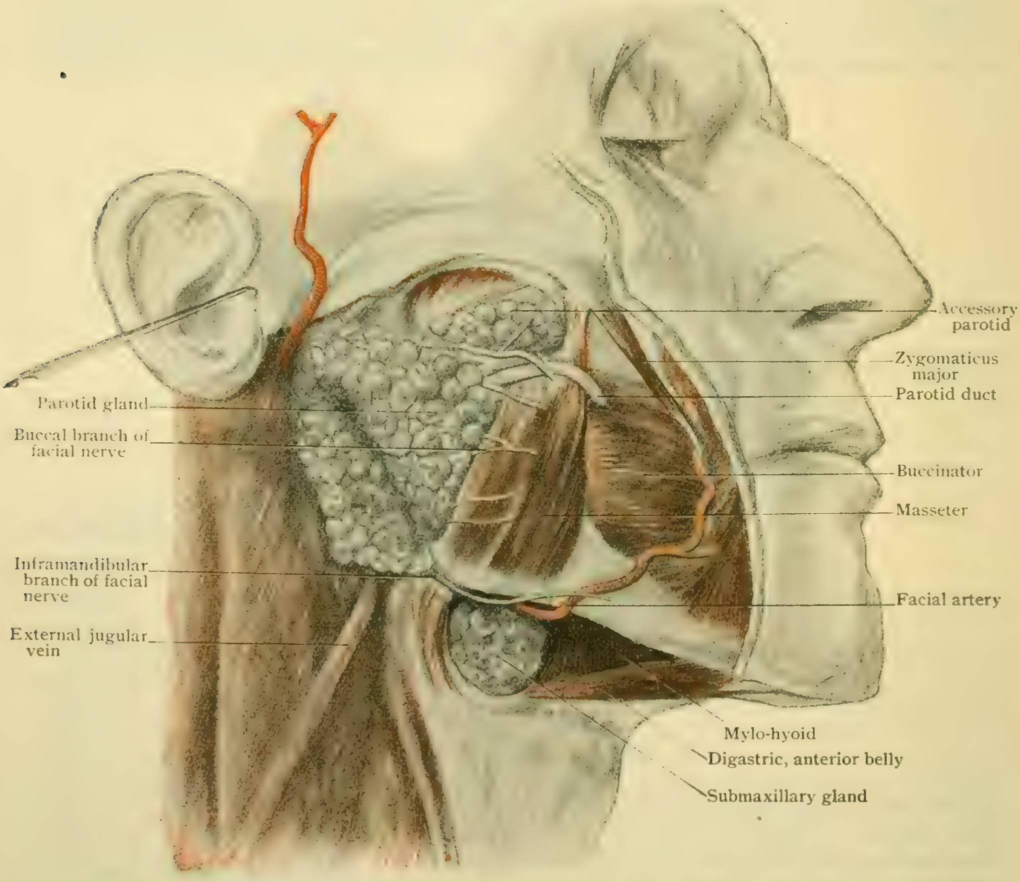
[1] Stahr: Zeitschrift für Morph. und Anthrop., Bd. iv., Heft 2, 1902.
[2] The *sublingual bursa* alleged to exist on either side of the frenum has not been described, since it is at most extremely uncommon.

THE SALIVARY GLANDS.

These, besides the mucous follicles of the mouth, are the *parotid*, the *submaxillary*, and the *sublingual glands* of the two sides. They are all reddish gray in color and of about the same firmness, excepting the parotid, which is denser.

The Parotid Gland.—The parotid is the largest of the salivary glands, weighing from 20–30 gm., with a considerable range beyond these limits. It is situated behind the upper part of the ramus of the lower jaw, which it overlaps both within and without. Its limits in both directions are very variable. The prolongation forward over the masseter muscle may become nearly distinct from the rest of the gland,

FIG. 1343.



Superficial dissection, showing parotid and submaxillary glands undisturbed.

and is then known as the *socia parotidis*. The *sheath* of the parotid is a strong fibrous envelope continuous with the cervical fascia in front of the sterno-mastoid, closely applied to the glandular substance and continuous with the partitions that pass through the organ, so that it can be dissected off from the gland only with difficulty. The parotid is divided into many small compartments or lobules by these resisting septa of fibrous tissue, the quantity of which gives it toughness. The shape of the parotid, as well as its size, is variable, since it grows where it can among more or less resisting structures. Its shape and relations, therefore, may be considered together.

Relations.—The parotid occupies a cavity bounded in front by the ramus of the jaw, covered by the masseter and internal pterygoid muscles ; behind by the

external auditory meatus, the tympanic plate, the base of the styloid process, and the front of the atlas. These two walls meet above at the Glaserian fissure. The posterior wall is prolonged laterally by the posterior belly of the digastric, the stylo-hyoid, and more externally by the sterno-mastoid muscles. The styloid process as it descends becomes internal, and the stylo-glossus and stylo-pharyngeus, together with the fascia known as the stylo-maxillary ligament, bound the posterior part of the gland internally. In front of the styloid process there is no wall to the space occupied by the parotid, the gland resting against the areolar tissue mixed with fat that lies on the outer wall of the pharynx. The widest part of this cavity is at the surface, where the fascia is connected with the capsule of the gland. The largest expanse of the parotid is, therefore, external. It overlaps the jaw and may reach down to the angle and be separated merely by fibrous tissue from the submaxillary gland. A constant, but very variable, prolongation on the face below the zygoma accompanies the duct. The parotid gland reaches upward between the joint of the jaw and the external auditory meatus and tympanic plate. Internally it lies against the structures above described, always resting on the inner side of the internal pterygoid muscle and extending to the great vessels and nerves which separate it from the side of the pharynx. There may or may not be a higher prolongation inward through the space in front of the styloid process. The internal carotid artery, internal jugular vein, and pneumogastric nerve are close against the lower part of the inner surface of the gland. The external carotid artery enters the gland from the inner side and divides into its temporal and internal maxillary branches, besides giving off the posterior auricular, and sometimes the occipital arteries, within its substance. The external jugular vein is formed within the gland and emerges from its lower side. Near the skull the great vessels and nerves are separated from the gland by the styloid process. The facial nerve enters the gland on its posterior side and passes through it obliquely so as to become more superficial as it travels forward, lying external to the external carotid artery and jugular vein. Before emerging from the gland the facial nerve breaks up into its two great divisions, the branches of which begin to subdivide within the glandular mass. The auriculo-temporal nerve also passes through the upper part of the gland, emerging on its outer aspect. A varying number of lymphatic glands lie in the substance of the parotid, mostly in the more superficial part. They are small and not easy to find. A larger one, said by Sappey to be constant, is in the gland just in front of the ear.

The **parotid** or **Stenson's duct** is formed by two chief tributaries, and emerges from the front of the gland, above its middle, running forward and a little downward across the masseter muscle to turn in sharply at its anterior border. It then crosses a collection of fat and runs obliquely through the buccinator muscle and the oral mucous membrane to empty into the vestibule of the mouth opposite the second, often the first, superior molar tooth. The length is some 40 mm. and the diameter 3 mm. The termination is a mere slit. Its walls are firm and resistant. The general direction of the duct is that of a line from the lower side of the concha of the ear to midway between the border of the nostril and the red edge of the lip. The transverse facial artery lies above it, on leaving the gland, and a plexus of veins surrounds it.

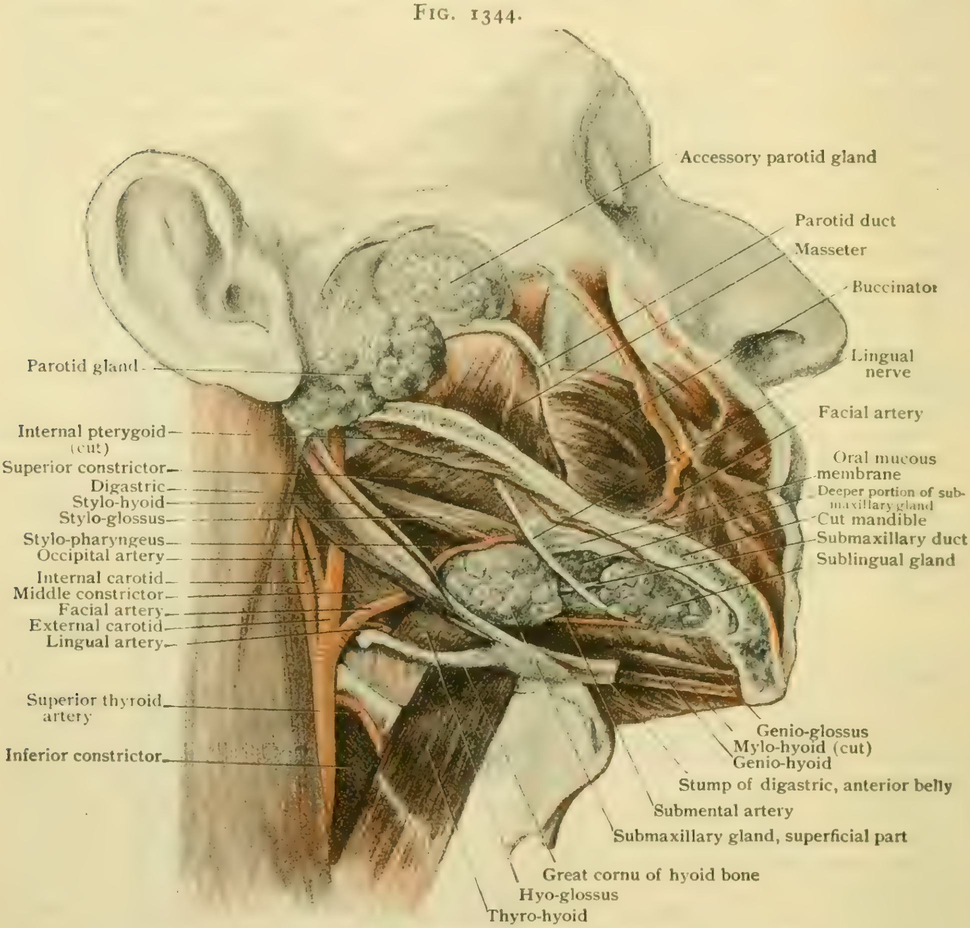
Vessels.—The *arteries* of the parotid gland are derived from several sources; although numerous, none of them is large. Besides several small branches from the external carotid itself while in the gland-substance, there are twigs from the temporal, especially from its transverse facial branch, from the posterior auricular, the internal maxillary, and probably from an occasional branch that may pass through the gland. The *veins* form quite a plexus through the gland and open into the system of the temporo-maxillary and of the external jugular. Of the *lymphatics* much remains to be learned, but they probably empty into both the deep and the superficial cervical nodes.

Nerves are from the facial, auriculo-temporal, and great auricular, besides sympathetic fibres from the carotid plexus.

The Submaxillary Gland.—This gland, weighing from 7–10 gm., lies largely under cover of the lower jaw, just before the angle, in a fossa on the inner side of the bone. As, however, the skin is carried inward under the jaw at this

point, the gland appears on the surface. It projects but little, if at all, on the outer side of the jaw, but curls around the posterior border of the mylo-hyoid muscle and extends for some distance in the floor of the mouth, under the mucous membrane, in the angle between the mylo-hyoid and the hyo-glossus, sometimes reaching the sublingual gland (Fig. 1344). It lies in a capsule derived from the cervical fascia, which is so loosely attached that the gland can easily be isolated. The anterior end of the posterior belly of the digastric and of the stylo-hyoid pass behind and beneath it. The hypoglossal nerve and the lingual vein lie beneath it, as does the first part of the lingual artery, until the latter passes under the hyo-glossus. Its sublingual branch runs along the inner side of the prolongation of the gland,

FIG. 1344.



Deeper dissection, showing relations of salivary glands.

to which it sends vessels. The facial artery lies beneath the gland before reaching the border of the jaw. The facial vein is superficial to it. The lingual nerve lies above the prolongation.

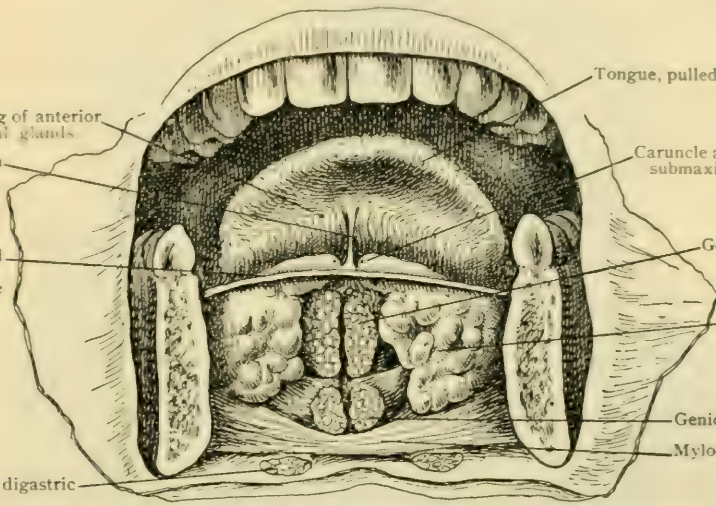
The **submaxillary** or **Wharton's duct** runs from the front of the main body of the gland along the floor of the mouth under the mucous membrane, often accompanied externally by the prolongation of the gland. It is from 4–5 cm. long, with a diameter of 3 mm. Its walls are decidedly thinner than those of the parotid duct. Anteriorly it rises to open into the mouth by a little papilla on the side of the frenum linguæ, the last few millimetres running in a fold of mucous membrane. The lingual nerve passes under the duct from without inward soon after it leaves the gland. The sublingual artery is beside it and a plexus of veins around it.

Vessels.—The *arteries* of the submaxillary gland are derived from the facial and the sublingual branch of the lingual. The *veins* are from the corresponding ones. The *lymphatics* go to the submaxillary glands.

Nerves.—The gland receives filaments from the sympathetic plexus accompanying the facial artery, from the lingual nerve, and from the submaxillary ganglion.

The Sublingual Gland.—This differs from the two preceding glands in having no capsule. It lies in loose areolar tissues on the mylo-hyoid muscle, at the front part of the sublingual space. Its weight is 3 or 4 gm. Each gland rests internally against the genio-glossus, and anteriorly they touch one another. They are more readily separated into lobes than the others. Testut regards them as aggregations of separate glands. The sublingual glands are covered by the mucous membrane of the floor of the mouth, which they press upward into rounded swellings on either side

FIG. 1345.



Section across anterior part of floor of mouth, showing relations of sublingual glands to mucous membrane and muscles.

of the beginning of the frenum. The lingual nerve and the submaxillary duct are on the inner side. The **sublingual** or **Rivinus' ducts** vary in number from four to twenty or more. They open for the most part in the floor of the mouth, but some may join Wharton's duct. *Bartholin's duct* is an inconstant one, larger than the others, that usually opens close to the outer side of Wharton's duct, which it follows.

Vessels.—The *arteries* are from the sublingual branch of the lingual and the submental branch of the facial, which latter sends minute twigs through the mylo-hyoid muscle. The blood escapes into the ranine *vein*. The *lymphatics* run to the submaxillary nodes.

Nerves are from the sympathetic, the lingual, the submaxillary ganglion, and, according to many, from the chorda tympani.

STRUCTURE OF THE SALIVARY GLANDS.

The three chief salivary glands possess in common the tubo-alveolar type of structure; depending upon the character of their secreting cells and products, the functionating organs represent both the serous and mucous varieties. The parotid is a pure serous gland ; the submaxillary is a mixed one, the alveoli containing serous cells predominating ; the sublingual, also a mixed gland, consists chiefly of mucous alveoli, the serous cells being limited to the marginal groups constituting the demilunes of Heidenhain.

The **parotid gland** consists entirely of serous alveoli, although mucus-producing acini may occur in the accessory lobules situated along the duct of Stenson. The primary lobules are made up of alveoli, from .015 to .020 mm. in diameter, lined with epithelial cells, which are somewhat pyramidal in form, since they are broader next the basement membrane and narrower towards the cleft-like lumen. The resting cells, fresh and examined without the addition of reagents, appear filled with numerous minute, glistening granules which lie embedded within a less strongly refracting substance. The granules, however, are readily affected by reagents, often undergoing partial or complete solution; hence the reticulated appearance of the protoplasm frequently observed in glandular epithelium after fixation. The nuclei of the serous cells are usually of spherical form and contain distinct nucleoli and delicate

FIG. 1346.

Section of small lobule of parotid gland. × 80.

chromatin net-works. The system of excretory canals begins at the alveoli as the intermediate tubules, which in the parotid are relatively long, about .010 mm. in diameter, and lined with low, flattened cells, directly continuous with the taller alveolar epithelium, on the one hand, and with that of the intralobular ducts on the other. The latter, or *salivary tubules* of Pflüger, of larger diameter (about .035 mm.) than that of the immediately preceding or succeeding segments of the canal, are clothed with a single layer of columnar cells, some .014 mm. in height, which present a peculiar differentiation into an inner and an outer zone. The former, next the lumen of the tube and containing the nucleus, appears finely granular or almost homogeneous, while the outer or basal zone exhibits a longitudinal striation composed of rows of minute granules. After treatment with certain reagents, the striated zone

breaks up into delicate rod-like processes, in recognition of which the cells lining the intralobular tubules are often designated rod epithelium. An active secretory rôle has been ascribed to these cells, R. Krause[1] having succeeded in demonstrating an excretory function by means of sodium sulphindigotate. The interlobular and interlobar ducts gradually increase in size and possess a lining of columnar cells which are usually arranged as a single layer. In the larger canals, however, the epithelium consists of two imperfect rows, since smaller cells lie next the basement membrane, wedged in between the larger typical elements. The columnar cells continue until near the termination of the main excretory duct, where they give place to the stratified squamous epithelium prolonged from the oral mucous membrane.

FIG. 1347.

Section of parotid gland, showing serous alveoli. × 270.

The **submaxillary gland** differs in structure from the parotid in possessing both serous and mucous alveoli, the latter forming approximately one-fifth of the entire organ. The alveoli containing serous cells correspond closely with those of the parotid, being from .020 to .030 mm. in diameter and filled with elements loaded with minute granules. Not infrequently the cells exhibit differentiation into an inner granular and an outer almost granule-free zone. The mucous alveoli are often somewhat larger than the serous, reaching a diameter of .040 mm. or more. The mucus-producing cells present the usual appearance and share the acinus with typical demilunes consisting of cells identical with those lining the serous alveoli. The mucous acini are directly connected with those of the serous type.

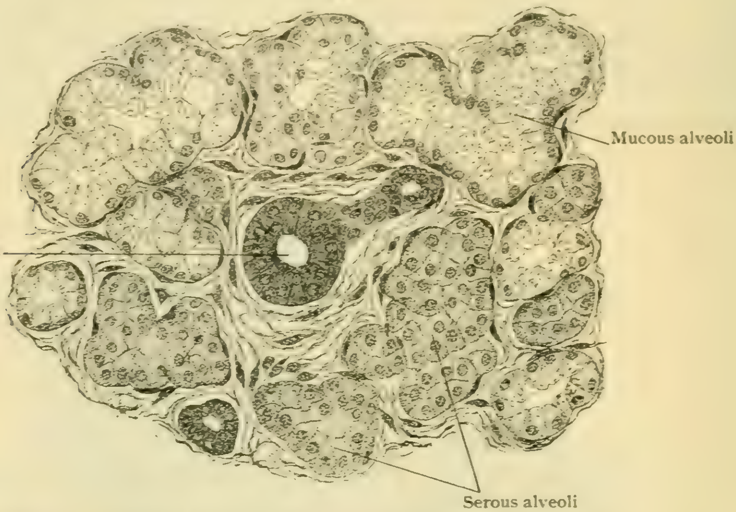
Intermediate tubules connect alveoli of both kinds with the intralobular canals; those beginning in mucous acini are shorter (.035–.060 mm.) and less richly branched than the tubules originating in serous alveoli. The latter measure from .060–.140 mm. in length, and repeatedly divide ; they are lined with low cubical cells which are gradually transformed from the alveolar epithelium in contrast to the abrupt transition seen in the tubules connected with mucous acini. The cells lining the intralobular tubules of the submaxillary gland exhibit the characteristic rod-like striation seen in the parotid, the rod-epithelium sometimes containing yellowish pigment granules. The interlobular and interlobar ducts resemble those of the parotid gland. The chief excretory duct possesses, in addition to a subepithelial elastic layer, a weakly developed stratum of longitudinally disposed involuntary muscle. Goblet-cells appear between the columnar elements lining the duct.

The **sublingual gland,** being of the mixed mucous type, resembles in structure the labial and buccal glands, and consists of a series of individual lobules, opening by half a dozen or more separate ducts, rather than a compact single organ. In com-

[1] Archiv f. mikro. Anat., Bd. xlix., 1897.

mon with other mucous glands, the sublingual lobules do not possess intralobular tubules lined with the characteristic rod-epithelium. The interlobular ducts subdivide into smaller canals which extend within the primary lobules and give off wider passages lined with cubical epithelium. Towards the end of these terminal canals

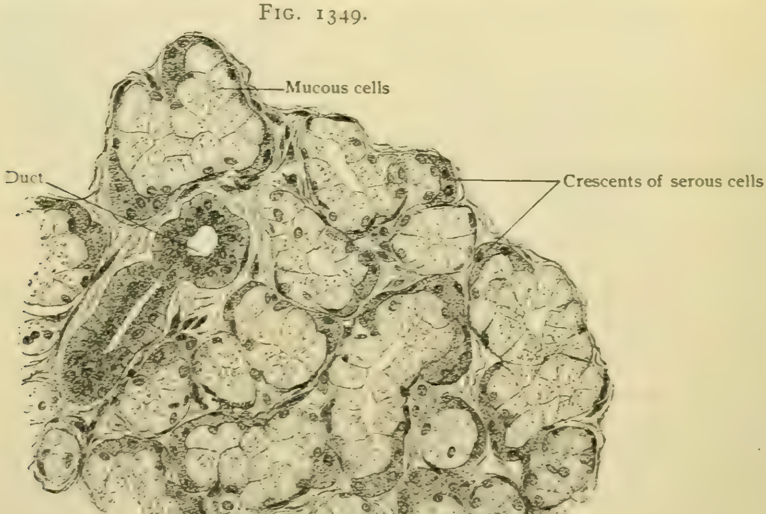
FIG. 1348.



Section of submaxillary gland, showing serous and mucous alveoli. × 270.

the mucous cells appear, at first isolated or in groups, increasing in numbers until they form the entire lining of the passage and become the secreting elements occupying the tubular alveoli of the gland. The latter vary from .030–.060 mm. in diameter, and are clothed with cells averaging .015 mm. high. The condition of the

FIG. 1349.



Section of sublingual gland, showing serous cells grouped as crescents. × 270.

alveoli as regards the mucus-bearing cells varies greatly even in the same lobule. At times an entire primary lobule is composed of acini filled with mucous cells ; at others empty and gorged alveoli alternate, or the depleted acini may predominate. Uncertainty as to the presence of the demilunes also exists, since these may be absent in

certain well-developed alveoli filled with large mucous cells, or they may be present in considerable numbers. Mucous cells are much less numerous in the sublingual glands of young infants than in the adult organ. The relatively wide lumen of the alveoli and the more reticulated appearance of their epithelium serve to distinguish the exhausted sublingual gland from the parotid of similar condition.

The normal secretions of the oral glands, mucous as well as serous, contain no formed elements; occasionally accidental granules or cell remains are present. The characteristic spherical so-called *salivary corpuscles* which occur in varying numbers in the mixed oral secretion have no relation to the salivary glands, since they are only modified leucocytes escaped from the lymphoid tissue of the faucial and lingual tonsils. On gaining the oral cavity, these cells are affected by the saliva and become greatly swollen, the granular remains of their cytoplasm exhibiting molecular motion in a marked degree.

Development of the Oral Glands.—The earliest traces of the *salivary glands* are seen during the second fœtal month. The anlage for the submaxillary gland first appears about the sixth week; next that for the parotid about the eighth week; a little later that for the sublingual. The parotid anlage develops from the oral ectoblast along the lateral groove separating the upper and lower jaws. The submaxillary and sublingual glands arise from a ridge-like anlage of the buccal epithelium occupying the furrow marking the angle between the tongue and the floor of the mouth, the anlage for the sublingual lying nearer the tip of the tongue. At first the parotid and submaxillary lie about equally removed from the oral opening, but later migration occurs, the former passing backward and the latter forward.

The development of the gland in each case begins as a solid cylindrical outgrowth from the deeper layer of the oral epithelium, which presents a local thickening. The cylinder rapidly lengthens and branches, so that by the eighth or tenth week the submaxillary and parotid glands respectively consist of a main stalk and terminal buds. The anlage of the sublingual gland gives off epithelial buds on acquiring a length of about 1 mm. The primary sprouts of the anlage subdivide and eventually become the smaller ducts and the glandular tissue. Meanwhile the immediately surrounding mesoblast undergoes condensation, and contributes the connective-tissue envelope with its prolongations between the lobules and acini supporting the blood-vessels and nerves. Towards the close of the third month, while the gland-tubules are still solid, the lumen of the future main excretory duct appears in the epithelial cylinder, extending from the free surface towards the alveoli. The latter acquire their lumen during the fifth month.

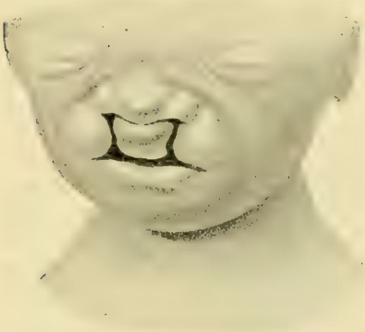
The *smaller oral glands*, including those of the lips, cheeks, tongue, and palate, develop much later than the larger salivary, since their anlages appear during the fourth month. The details of their development correspond in general with those attending the formation of the larger oral glands.

PRACTICAL CONSIDERATIONS: THE MOUTH.

The chief congenital deformities of the mouth are harelip and cleft palate. *Harelip* results from a failure of the developmental procedures concerned in forming and differentiating the nasal and buccal cavities. These processes have already been described in connection with the formation of the face (page 59). Upon the downgrowth of the fronto-nasal process depends the formation of the vomer, the perpendicular plate of the ethmoid and the external nose, and of the intermaxillary bone and that portion of the upper lip corresponding to the four incisors. The partition separating the nasal from the oral cavity, later the hard and soft palates, is formed by the union of the horizontal palatal plates from the buccal aspect of the two maxillary processes (Fig. 76). When the frontal and maxillary processes fail to unite on one side, single harelip results, the cleft in one side of the lip lying opposite the space between the upper canine and lateral incisor, or between the latter and the central incisor. When union between the maxillary and the frontal processes fails on both sides, double harelip follows, the lateral incisors often being absent and the intermaxillary bone with the central incisors and the median portion of the lip occupying a position beneath the nasal septum.

Cleft palate is caused by faulty union between the palatal processes of the maxillary arches. The cleft is always in the middle line, and may involve only the uvula and soft palate, may extend to the posterior margin of the intermaxillary bone, or may diverge from that point on one or both sides and run forward through the alveolus, being then associated with single or double harelip, the cleft or clefts in the alveolus corresponding in position to the deficiencies in the lip (page 63).

FIG. 1350.



New-born child with double harelip.

The Lips.—The mucous membrane of the lips and the adjacent skin are often affected by herpes labialis, which may be associated with gastro-intestinal disturbance, or may be purely neurotic in its origin, following mental depression or anxiety. It is found in the distribution of the second and third divisions of the fifth pair which supply sensation to the upper and lower lips respectively. The vascularity of the lips, while it leads to excessive exudate and large swelling after contused or lacerated wounds, favors rapid healing and the avoidance of infection after surgical wounds. In few places equally exposed to contact with infectious organisms was healing by "first intention" so common before the introduction of antisepsis. The coronary arteries run between the mucous membrane and the orbicularis oris. They are therefore more often severed by wounds extending from within outward—usually made by the teeth—than by those beginning externally. The coronaries anastomose very freely. In arresting hemorrhage from them by direct ligature both ends should be tied. If a wound of the lips is united by pins and figure-of-eight sutures, the pins should be passed close to the inner edges of the wound so that the coronaries may be compressed between the pins and the sutures. The vascularity of the lips renders chancres of that region, like those of the face, exceptionally large both in depth and in superficial area. It also adds greatly to the extent of furuncular or carbuncular infection in this region, the occurrence of which is favored by the large number of hair and sebaceous follicles present. The danger of infective sinus thrombosis (intracranial) as a result of such infection here or elswhere on the face is much increased by the free anastomosis between the valveless facial vein and its tributaries and the ophthalmic vein, which is also without valves. As might be expected, nævi are frequent in the lips. In the male the lower lip is the favorite seat of epithelioma. Either infection or diminished tissue resistance from minor traumatisms, or from tobacco-irritation in smokers, is supposed to explain this clinical fact. The mucous glands of the lip are not rarely the seat of retention-cysts from obstruction of their ducts.

The Gums.—The mucous membrane of the lips is continuous with that covering the fibrous tissue of the gums, but the latter is slightly less vascular and much less sensitive. The gums are sometimes congenitally hypertrophied ; the condition is usually associated with defective or aberrant developmental processes often affecting the mentality. They are also often found hypertrophied in edentulous old persons or in persons with badly fitting artificial dentures. They are the frequent seat of inflammation from various causes, the most common of which are the decomposition of food and the deposition of calcium salts—tartar—about the necks of the teeth. Infection frequently follows the hyperæmia produced by these forms of irritation. When it is confined to the space between the mucous membrane and the fibrous tissue, it causes a limited superficial abscess,—"gum-boil ;" if it gains access to the subperiosteal space, it may cause a form of alveolar abscess, the usual variety of which is, however, due to infection secondary to dental caries, and is situated about the root of a tooth (*vide infra*).

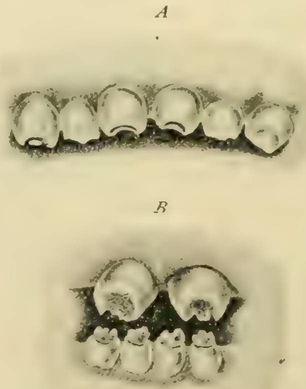
Tartar is found most abundantly near the openings of the submaxillary and sublingual ducts,—*i.e.*, near the inner surfaces of the lower incisor teeth. Mercury and lead cause gingivitis probably by the actual presence of their salts in quantity sufficient to act as irritants, their deposition from terminal capillaries being favored by the

frequent hyperæmia due to the vascularity and the warmth and moisture of the region, together with slight but repeated trauma during mastication. The gingivitis of scurvy or of purpura is merely a local evidence of a constitutional condition, and is hemorrhagic rather than inflammatory.

During dentition the resistance of the gums may cause backward pressure upon the nervous and vascular supply of the pulp of the tooth, giving rise to some pain and sometimes to grave reflex disturbances, especially in infants. The insensitive gum then becomes exceedingly tender and is swollen and œdematous. The wide-spread relations of the fifth nerve render long-continued irritation of its dental branches dangerous. "Lancing" the gums is the obvious remedy. It is especially apt to be needed over the molars and cuspids, and the lines of incision should be planned so as to release fully the presenting surfaces of those teeth.

The Teeth.—*Alveolar Abscess.*—The line of penetration in dental caries is often in the direction of the pulp, through which infection extends to the "apical space" between the root of the tooth and its socket, containing the vessels and nerves and some loose connective tissue. This space soon becomes filled with pus, the cavity enlarges, and reaches the compact bone on the surface of the alveolus (the density of which impedes the process somewhat); but finally the bone is perforated, usually through the thinner external or buccal wall of the alveolus. The periosteum usually yields opposite the gum immediately over the apex of the tooth, where it is reinforced by mucous membrane only. If the root of the tooth is a long one or the abscess has gone deeply into the bone, the pus may reach the periosteum at a point where it is supported by the muscular and fibrous tissues of the cheek. The pus may then strip the periosteum from the bone so as to cause extensive necrosis. This is less likely to occur in the alveolus of the upper jaw or in the hard palate, on account of their free blood-supply derived from several sources. In cases of this type in either jaw, a sinus followed by a depressed, adherent, and disfiguring cicatrix is liable to result (Roughton). Alveolar abscess is also influenced in its course by the situation of the particular tooth involved. In the maxilla, abscesses connected with the canines or incisors may point into the nasal cavity or on the under surface of the hard palate. The pus is more likely, however, to descend by gravity alongside of the root to the edge of the gum, or to follow the canal of the root into the pulp-cavity. Abscesses connected with the upper molars, especially the first, or, more rarely, those in relation to the cuspids, may point in the antrum. They occasionally open on the face in front of the anterior border of the masseter. The relation of the apex of the root to the mucous membrane of the gum often determines the point of opening. If the apex in the case of the lower teeth is above, or in that of the upper teeth is below the line of reflection of the mucous membrane from the cheek to the gum, the abscess tends to point in the mouth. If the contrary is the case, pointing on the face or neck may result.

FIG. 1351.



Characteristic teeth of inherited syphilis. *A*, upper permanent central incisors deeply notched; lateral incisors show no defect; right canine has deep notch; exposed dentine has become discolored. *B*, upper incisors only recently erupted; central notch marked out but not yet cleared out by breaking away of unprotected dentine; four lower incisors present peg-like excrescences due to loss of enamel and exposure of dentine. (*Hutchinson.*)

In *syphilis* the first teeth exhibit malformations characteristic of perversions of nutrition or of inflammation of the gums sufficiently severe to affect the blood-supply to the tooth-sacs. The enamel may be deficient, opaque or chalky, the dentine soft or friable, the teeth irregular in size and uneven in position.

The permanent teeth may show the same general aberrations as to growth and nutrition that are produced by stomatitis from digestive derangements or from local irritation. After mercurial stomatitis, for example, the teeth are irregularly outlined, horizontally seamed, scraggy, malformed, deficient in enamel, separated too widely, and dirty yellow in color.

The typical (and pathognomonic) syphilitic teeth—"Hutchinson's teeth"—are the upper permanent central incisors. The type is observed in its perfection soon after the extrusion of these teeth. The essential characteristic is a crescentic notch (Fig. 1351, *A*) in the free edge of the tooth, the anterior border of the notch being bevelled from above downward and from before backward,—*i.e.*, at the expense of the anterior surface and border of the tooth. Typical Hutchinson's teeth are, furthermore, reduced in length and narrowed,—"stunted;" their angles are rounded off, the lateral and inferior borders merging in a curved line; they deviate from normality in direction, their axes being obliquely convergent, or more rarely divergent, instead of parallel.

The other surgical relations of the teeth and of the dental tissues which are of chief importance are concerned with the new growths originating in dental elements. The *odontomata* are divided by Sutton as follows, and the classification should be remembered in studying the anatomical development of the teeth:

(1) Persistent portions of the epithelial sheath (page 1561), taking on overgrowth, may give rise to an *epithelial odontome* (multilocular cystic tumor). (2) Expansion of the tooth-follicle with retention of the crown or root of an imperfectly developed tooth results in a *follicular odontome* (dentigerous cyst). (3) Hypertrophy of the fibrous tooth-sac causes a *fibrous odontome*, especially frequent in rickets, which usually affects the osteogenetic fibrous membranes. (4) If the foregoing hypertrophy occurs and the thickened capsule ossifies, a *cementome* results. (5) If this takes place irregularly, small malformed teeth—"denticles"—may form in large numbers and occupy the centre of the tumor (*compound follicular odontome*). (6) Tumors of the root, after the full formation of the crown, are of necessity composed of dentine and cementum only, enamel not entering into them (*radicular odontomata*). (7) Tumors composed of irregular conglomerations of enamel, dentine, and cementum, and often made up of two or more tooth-germs fused together, constitute *composite odontomata*. All these growths can be understood only by careful study of the normal development of the teeth. They are rarely diagnosed before operation, which is therefore in some cases needlessly severe. Sutton says very truly, "In the case of a tumor of the jaw the nature of which is doubtful, particularly in a young adult, it is incumbent on the surgeon to satisfy himself, before proceeding to excise a portion of the mandible or maxilla, that the tumor is not an odontome, for this kind of tumor only requires enucleation. In the case of a follicular odontome it is usually sufficient to excise a portion of its wall, scrape out the cavity, remove the tooth if one be present, stuff the sac, and allow it to close by the process of granulation."

The Roof of the Mouth and the Palate.—The mucous membrane covering the hard palate is so fused with the periosteum as practically to be inseparable from it. It is dense, resistant, and comparatively insensitive. A vertical transverse section of the roof of the mouth (Fig. 1294) shows the mucous membrane to be thickest laterally and thinner in the median line.

Cleft palate (page 1590) results from imperfect fusion between the horizontal palatal plates of the maxillary processes of the first visceral arch. It is always in the middle line. It may involve the soft palate and uvula. If it extends forward as far as the alveolus, it follows the line between the maxilla and the premaxillary bone, usually terminating in a harelip (page 1589) opposite the interval between the lateral incisor and canine teeth. If it separates the maxillæ on both sides from the premaxillary bone, it is almost always associated with double harelip.

The toughness of the muco-periosteum of the hard palate facilitates the formation of flaps in operations for the closure of such a cleft. In dissecting up the flaps it is well to keep close to the bone and to avoid the descending or posterior palatine branches of the internal maxillary artery. These vessels, on which the nutrition of the flaps as well as of the bone depends, emerge from the posterior palatine canal at a point on the line of junction of the hard and soft palates 8 mm. (⅓ in.) anterior to the hamular process and a little to the inner side of the last molar tooth. They run forward in a shallow groove just internal to the outer border of the hard palate. They are nearer to the bone than to the mucous surface, but their pulsations can often be felt by the finger. For these reasons incisions in uranoplasty

should be made close to the alveolus and the bone should be hugged as the flaps are raised. In troublesome bleeding from these arteries the posterior palatine canal may be plugged by a sharpened stick, which should previously be sterilized.

When the cleft involves only the soft palate, staphylorrhaphy is required. The muscles that tend to pull the edges apart are the tensor palati and levator palati. The former turns around the hamular process and passes almost horizontally towards the median line, the latter lies close to the posterior surface of the soft palate and runs obliquely from above downward and inward. These muscles may be divided by various incisions, the simplest being a section of the velum near its lateral border and parallel with the cleft.

The hamular process may be felt behind and a little internal to the last molar tooth. The pterygo-mandibular ligament may be felt passing from the hamular process to the posterior end of the mylo-hyoid ridge of the lower jaw just behind the last molar tooth. The fold of mucous membrane covering it may be seen when the jaws are separated widely. The lingual branch of the fifth nerve may be felt between the mucous membrane and the bone anterior to the base of the pterygo-mandibular ligament and below the last molar. With a finger passed behind the last molar, the swell of the alveolar ridge can be recognized as it narrows to pass into the ramus. The nerve is below and parallel with that ridge. It is sometimes divided for the relief of the unbearable pain of carcinoma of the tongue. This may be done by entering the point of a curved bistoury a little less than three-quarters of an inch behind and below the last molar and cutting on the bone towards the tooth.

Fig. 1352.

Dissection of under surface of tongue and sublingual space; mucous membrane removed and tongue drawn upward and forward from mouth.

The Floor of the Mouth.—The mylo-hyoid muscle, extending from the symphysis to the last molar tooth, separates the buccal cavity from the neck. Infections or neoplasms beginning above this muscle are first recognized through the mouth; those below it in the neck. The sublingual gland, for example, lies altogether above it and directly beneath the mucous membrane of the floor of the mouth; the duct of the submaxillary gland occupies a similar position. Affections of these structures, therefore, manifest themselves in the mouth. The submaxillary gland, however, lies partly beneath the posterior border of the mylo-hyoid. Accordingly, disease of this gland is apt to show most markedly beneath the jaw (Fig. 267, page 247). "Ludwig's angina" (page 553) may spread to the loose connective tissue between the mylo-hyoid muscle and the mucous membrane of the floor of the mouth. That membrane is reflected from the under surface of the tongue to the alveoli and is divided anteriorly by the frenum linguæ. On either side of this may be seen the ridges indicating the situation of the sublingual glands, and close to the frenum at the inner end of the ridge the papillæ at the opening of Wharton's ducts, into which a fine probe may be passed (Fig. 1352). The inelastic character of the walls of the latter should be remembered as explaining in part the intense pain caused by an impacted submaxillary calculus. This is also in part due to the close relation of the duct to the

lingual nerve. The relation of that nerve to the floor of the mouth posteriorly has already been described (page 1249).

The fold of mucous membrane constituting the frenum may be abnormally short and prevent the free movements of the tongue, interfering with sucking during infancy and with articulation later. When its division is necessary, it should be cut through close to the jaw, and with blunt-pointed scissors directed away from the tongue so as to avoid the ranine veins which may be seen close to it on the under surface of the tongue.

The ranine arteries lie farther out and are more deeply situated, being placed beneath two converging raised fringed lines of mucous membrane, the *plicæ fimbriatæ*.

A *sublingual bursa* is described by Tillaux as a triangular space situated between the genio-hyo-glossus and the mucous membrane, its tip being at the frenum, its base at the sublingual gland. Its existence, by no means constant, is said by Tillaux to explain the occurrence of the acute cystic tumor (*grenouillette*), "acute ranula," which is occasionally met with in this region.

Ranulæ—ordinary retention cysts—are common in the floor of the mouth, and branchiogenic cysts, due to the incomplete closure of the first branchial cleft, are sometimes found there.

The Cheeks.—The buccal limits of the cheeks are accurately indicated by the reflections of mucous membrane lining them. By making outward traction on the angle of the mouth that membrane can be seen and palpated, and ulceration, as from a jagged tooth or beginning epithelioma, or mucous patches, or abscess, or new growths, can easily be detected.

The papilla indicating the opening of the parotid duct may be seen or felt opposite the upper second molar tooth. A fine probe may be made to enter the duct for a short distance, the normal curves then interfering with its passage (Fig. 1343).

Lipoma originating in the "boule de Bichat" (page 493) can be recognized.

As the jaws are separated and closed the anterior border of the masseter may be seen and felt. The important structures of the cheek—the facial vein and artery and the parotid duct—are all anterior to this line (Fig. 691).

The Tongue.—Congenital deformity of the tongue is rare. Forked tongue —normal in some birds and reptiles and in seals—is rare; it is usually in association with other developmental defects, as cleft palate. Congenital absence has been noted (de Jussieu).

Macroglossia (*lymphangioma cavernosum*, Virchow) is a congenital affection in which the lymph-channels and lymph-spaces are dilated and the lymphoid tissue throughout the tongue, but especially at the base, greatly increased. The tongue may attain an enormous size, and has even, by pressure, caused deformities of the teeth and alveolar arches and luxation of the mandible. The foramen cæcum, indicating the junction of the pharyngeal and buccal parts of the tongue, is the superior termination of the fœtal thyro-glossal duct. "Ducts lined with epithelium have been found leading from the foramen cæcum to accessory glands about the hyoid bone. It is probably from these glandular and epithelial collections about the hyoid bone that certain deep-seated forms of cancer of the neck are developed. Some of these take the form of malignant cysts" (Treves).

The upper surface of the tongue has for centuries been the object of especial observation in disease. The practical value of these observations is not universally conceded, and too much weight has been placed upon them; but there can be no doubt that some help in prognosis and even in diagnosis in digestive derangements, in fevers, and in various toxæmias may be obtained by inspection of the tongue.

The "fur," so carefully studied, consists of a mixture of desquamated epithelial cells, food particles, and micro-organisms of various kinds overlying living epithelium which may be abnormally proliferating.

The surface between the circumvallate papillæ is apt to be the most heavily coated, either in health or disease, because it is the least mobile part of the tongue and is not kept clean by friction, as are the sides and tip. The appearance of

the coating and of the tongue itself varies greatly, but it may be said that *dryness* not due to mouth-breathing, but from deficient secretion, as in fevers; *darkness*, from decomposition and desiccation of the coating, or from imperfect oxygenation of the blood; *roughness*, from papillary overgrowth with marked epithelial proliferation and desquamation; *redness*, from epithelial denudation; and *stiffness*, *slowness*, or *tremulousness* in protrusion, from either thick, inflexible coating, muscular weakness, or mental hebetude, are uniformly regarded as unfavorable conditions.

Unilateral furring of the tongue has been observed in cases of dental caries, of fractured skull, and of intracranial disease, in all three instances the furring being on the side on which there was irritation of the branches of the fifth pair of nerves. In some of them it was confined to the anterior two-thirds of the upper surface,—*i.e.*, to the distribution of the lingual branch of the fifth (Hilton).

In tonsillitis the tongue will often be furred over its posterior part only—*i.e.*, the portion which, like the tonsil, receives its nerve-supply from the glosso-pharyngeal (Jacobson). Unilateral furring in the presence of toothache may be due partly to the instinctive immobilizing of that side of the tongue nearest the painful tooth (Hutchinson).

In chronic superficial glossitis the epithelium thickens at places into rounded, whitish patches, which are difficult to heal on account of the constant exposure to warmth, moisture, infection, and minor traumatisms, and the impossibility of securing rest. This condition (*leukoplakia*) may precede the development of epithelioma.

In rare cases the epidermis covering the filiform papillæ undergoes hypertrophy, producing the so-called "hairy tongue."

The lymphoid tissue behind the circumvallate papillæ, from overgrowth, forms an irregular rounded mass just beneath the mucous membrane,—the lingual tonsil,—which from its proximity to and interference with the epiglottis may require removal.

The connective tissue of the tongue is scanty, but is abundant enough to permit of great swelling in cases of acute glossitis, and this is favored by the vascularity of the organ. The cause is always infection through a surface solution of continuity either traumatic or during some disease attended by drying and fissuring of the tongue. On account of the vascularity, nævoid growths are frequent.

Carcinoma of the tongue is exceedingly common, and Treves calls attention to the fact that it usually affects the anterior two-thirds or that portion which is derived from the mandibular arch, as is the lower lip, which is also one of the commonest sites of epithelioma. Cancer of the fore part of the tongue may follow the lymphatics of that region into the submaxillary glands, or pass by the main lymphatic channels into the deep cervical glands. Those first demonstrably enlarged, whatever the site of the cancer, are apt to be in the group beneath and behind the angle of the jaw.

The pain in cancer of the tongue is almost always associated with what are described as "earache," "toothache," "faceache," and sometimes with spasm of the muscles of mastication. These symptoms are due to the connection of the lingual branch of the fifth pair with other branches of the third division of the fifth, especially the auriculo-temporal and inferior dental, with the tympanic branch of the glosso-pharyngeal, and with the chorda tympani from the facial.

Pressure upon, or disease of, the hypoglossal nerve may cause unilateral atrophy of the tongue. The various paralyses should be studied in connection with the nervous supply of the tongue.

As the tongue depends upon muscular and not ligamentous attachments for the preservation of its position in the mouth, its tendency to drop backward by gravity during complete anæsthesia or some other forms of profound unconsciousness in which muscular relaxation or paralysis occurs should not be forgotten. If it is allowed to fall back, the pressure on the epiglottis may close the opening into the larynx. During anæsthetization it is well to press the lower jaw well forward, carrying the tongue with it through the attachments of the genio-glossi, and to elevate the chin, which still farther advances the tongue and removes it from close proximity to

the epiglottis. Often this does not suffice, and direct traction on the tongue itself is required.

Excision of the entire tongue necessitates division of the muscles of the tongue, its connections by mucous membrane with the soft palate, the alveoli, and the epiglottis, the lingual arteries and veins, and the glosso-pharyngeal, lingual, and hypoglossal nerves.

In opening abscesses of the tongue the position of the lingual arteries—much nearer the lower than the upper surface—should be remembered.

Hemorrhage from wounds or during operation may temporarily be controlled by pressure from behind forward on the base of the tongue by two fingers thrust well below and behind it in the pharynx. By this procedure, or by forcing up the soft tissues between the inferior maxilla and the hyoid bone with the finger or thumb, the cut surface during partial excision may be brought well into view and the hemorrhage controlled while the vessels are sought and secured.

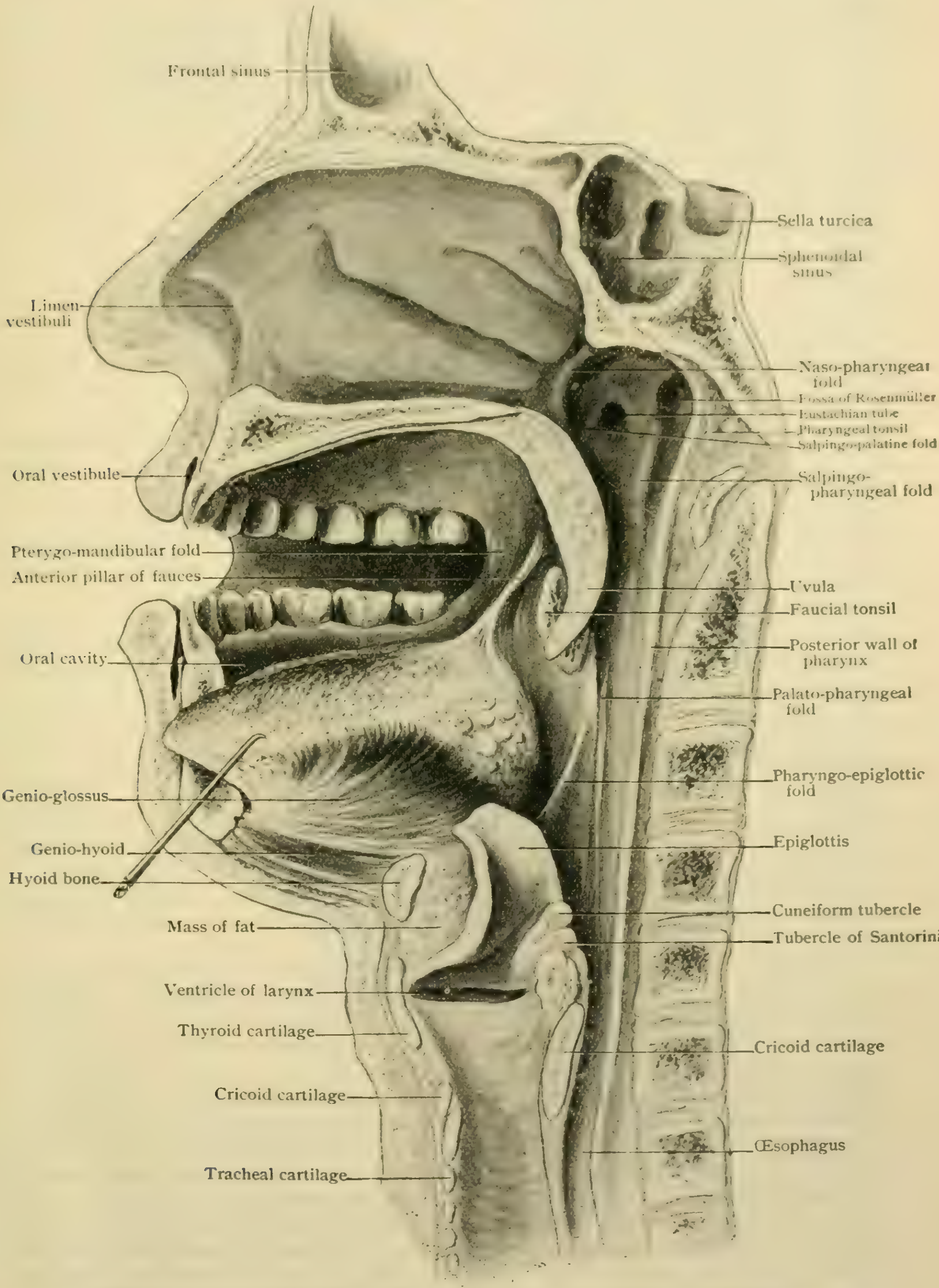
THE PHARYNX.

The pharynx is a bag, open in front, with musculo-membranous walls, lined with mucous membrane, extending from the base of the skull to the lower border of the larynx, near the level of the top of the seventh cervical vertebra. Thus it is bounded behind by the spine, covered by the prevertebral muscles and fascia, and by the basilar process of the occipital bone, which, especially in the median line, is separated by much areolar tissue, as well as by muscles from the posterior wall. The steep rise of the basilar process, together with the downward growth of the face, forms the deep recess known as the *naso-pharynx*. The roof is formed by a little of the front of the basilar process and by the back part of the basi-sphenoid. The anterior wall is formed by the back of the framework of the face, the soft palate, the back of the tongue, the hyoid bone, and the larynx. The pharynx communicates in front with the nasal chambers and the mouth ; the Eustachian tubes open into it on either side near the top ; and below it contains the opening of the larynx, behind which it passes into the œsophagus. The framework consists of the *pharyngeal aponeurosis*, a distinct fibrous membrane above, placed between the mucous membrane and the muscular layer, which grows weaker below and is continued into the gullet. This is attached above to the pharyngeal tubercle and to the occipital bone on either side of it, to the cartilage between the petrous portion of the temporal and the basilar process, to the Eustachian tube which passes over it, and to the base of the internal pterygoid plate. This fascia is wanting in front. The parts forming most of the anterior wall—the soft palate and the back of the tongue—are capable of changing their relations. The pharynx is enclosed by a layer of fascia, the *bucco-pharyngeal* (not to be confounded with the pharyngeal aponeurosis), the front part of which is connected with the pterygo-mandibular ligament and covers the buccinator muscle. This fascia lies beneath the parotid gland and mingles with the cobweb-like tissue of the carotid sheath to make a large amount of rather dense areolar tissue on either side. At the back it is very lax, allowing the pharynx to move on the smooth prevertebral fascia. The condition there approaches that of a serous bursa.

The pharynx is divided into the *naso-*, *oro-*, and *laryngo-pharynx* by folds on the anterior and lateral walls. The uninterrupted posterior wall is covered with smooth mucous membrane, which, behind the larynx, tends to be puckered into longitudinal folds. The *naso-pharynx* is that part above the free edge of the soft palate. The *oro-pharynx* communicates at the anterior pillar of the fauces with the mouth. The *isthmus*, a niche between the faucial pillars containing the tonsils, is its anterior part. It is separated from the laryngo-pharynx by the *pharyngo-epiglottic fold*, which extends from the epiglottis to the side of the pharynx, as more particularly described later. The length of the male pharynx is about 13 cm. (about 5 in.), which is rarely much exceeded. The greatest breadth (4–5 cm.) is near the top of the laryngo-pharynx, rather below the greater horns of the hyoid bone. The greatest breadth in the naso-pharynx, between the deepest points of the fossa of Rosenmüller, is 3.5 cm., or perhaps a little more. Behind the upper margin of the cricoid cartilage the breadth is not over 3 cm., below which it abruptly diminishes. The antero-

posterior diameter in the median line is greatest in the naso-pharynx,—about 2 cm. The back of the lower part of the soft palate is less than half that distance from the

FIG. 1353.



Sagittal section of head, slightly to right of median plane; tongue has been pulled down.

posterior pharyngeal wall. The greatest depth in this direction (3–4 cm.) is at the side, from the anterior pillar to the posterior wall. Behind the cricoid cartilage the

front and back walls are probably in contact. In the female several of these distances are smaller. Thus the pharynx is in horizontal sections at most levels a transverse cleft.

The **naso-pharynx**, broad from side to side and short from before backward, passes insensibly into the oro-pharynx when the soft palate is not raised so as to cut off communication. Anteriorly are the nasal openings, described with the nose. The separation of the two regions on the lateral wall is determined by the *naso-pharyngeal fold* which runs from the base of the skull to the beginning of the soft palate. This fold is very irregular in course and development. It occasionally is grooved so as to present a furrow. Sometimes the furrow takes the place of the fold and at other times the fold joins that in front of the *opening of the Eustachian tube.* This orifice is on a level with the end of the inferior turbinate bone and less than 1 cm. behind it. It is usually a triangular opening without a distinct border below, although it may be oval or even round. The longest diameter is about 1 cm. The end of the cartilage of the tube curves over the top of the opening from the front and descends along its posterior border, producing a strong fold of the mucous membrane, the *salpingo-pharyngeal*, which descends to be lost in the lateral wall of the oro-pharynx, or even sooner. The *salpingo-palatine fold* in front of the opening of the Eustachian tube is, as a rule, less prominent and very variable. It is formed above by the bent end of the cartilage, and below by a small band of fibrous tissue, the *salpingo-palatine ligament*, running from the cartilage into the soft palate. The *fossa of Rosenmüller* is a deep pocket at the angle of the pharynx between the posterior wall and the back of the projection of the cartilage of the tube. Its anterior and posterior walls are almost in contact and are often connected by accidental adhesions. This is the broadest part of the naso-pharynx. Adenoid collections—the *tubal tonsils*—are found in varying degree about the orifice of the tube, especially over the fold behind it. The belly of the levator palati muscle makes a prominence in the lateral wall below the tubal orifice.

The **oro-pharynx** opens into the mouth at the anterior pillar of the fauces. The posterior pillar, covering the palato-pharyngeus muscle, runs down the side of the pharynx as the *palato-pharyngeal fold.* It may be traced to the base of the superior horn of the thyroid cartilage, or, as is most common, it is lost on the lateral wall a little higher. The *pharyngo-epiglottic fold* above mentioned arises from the front of the epiglottis near the lateral edge and runs upward and backward across the pharynx. It may end soon, or it may reach the palato-pharyngeal fold, or, crossing this, may extend even as far as the salpingo-pharyngeal one. It contains muscular or tendinous fibres from the stylo-pharyngeus. If well marked, it may bound below the niche containing the tonsil. The anterior wall of the oro-pharynx is formed, the mouth being closed, by the posterior vertical part of the tongue. The respiratory tract, passing through the nose, and the digestive, passing through the mouth, cross each other in the oro-pharynx, so that the former is the anterior below this point.

The **laryngo-pharynx**, the lowest part of the pharynx, is, roughly speaking, the part below the level of the hyoid bone. It is separated from the oro-pharynx by the pharyngo-epiglottic fold. In the middle of it is the opening of the larynx behind the epiglottis and enclosed by the aryteno-epiglottic and interarytenoid folds. The *sinus pyriformis* is a depression on either side of the entrance of the larynx between the aryteno-epiglottic fold and the arytenoid cartilage internally and a part of the great wing of the thyroid cartilage and the thyro-hyoid membrane externally. It is open behind. The thin mucous membrane lining the sinus has a transverse fold, formed by the superior laryngeal nerve, in front between the hyoid bone and the thyroid cartilage. The lower part of the palato-pharyngeal fold is seen in frozen sections near the superior horn of the thyroid cartilage at the lateral aspect of the cleft, which is all that appears of the pharynx. The anterior wall behind the arytenoid cartilages and the structures between them slants backward as it descends. Behind the cricoid cartilage it is vertical. Here the pharynx narrows to join the œsophagus.

The **mucous membrane** of the pharynx is smooth, except for the elevations caused by collections of lymphoid follicles. It is more loosely attached and more

disposed to be thrown into folds in the lower part. Mucous glands, on the other hand, are numerous in the upper part, scarce below; they lie partly within the mucosa and partly in the submucous tissue and between the muscular bundles. The character of the pharyngeal epithelium varies in different localities. In the nasal pharynx the stratified ciliated columnar cells of the nasal fossa are continued as the covering of the pharyngeal mucous membrane, while the oro-pharynx is clothed with stratified squamous epithelium continued from the mouth. The last-named type of epithelium likewise covers the greater part of the laryngeal portion. The exact distribution of the two varieties of cells is subject to considerable individual variation. The ciliated columnar type extends laterally to include the openings of the Eustachian tubes, but lower down gives place to the squamous. By no

FIG. 1354.

Pharynx opened from behind; epiglottis turned back.

means the entire posterior surface of the soft palate is clothed with ciliated columnar cells, since the entire uvula and the edges of the palato-pharyngeal folds are invested with stratified squamous epithelium. The latter also covers the posterior wall of the pharynx and extends above as far as the vault. When covered with ciliated epithelium, the mucous membrane is redder, thicker, and contains more glands, but fewer papillæ, than in those parts in which the squamous cells prevail. While containing much lymphoid tissue, fat is limited to a few deeply seated lobules of adipose tissue.

Lymphoid Structures.—The upper part of the pharynx contains many lymphoid collections which make the surface uneven. They are much less frequent below. The larger and more constant masses are called "tonsils." These include the *faucial tonsils* in the oro-pharynx, between the pillars of the fauces, the *pharyn-*

geal tonsil in the upper part of the pharynx, the *tubal tonsils* at the openings of the Eustachian tubes, especially on the posterior fold, and the *lingual tonsil*, consisting of the scattered adenoid collections over the posterior third of the tongue. Many additional lymph-nodules are scattered over the sides and roof, so connected as to form a lymphoid ring at the upper part of the pharynx.

The **faucial tonsils** (Figs. 1326, 1353) are theoretically two almond-shaped masses of adenoid tissue, placed one on each side of the oro-pharynx, between the pillars of the fauces. The long diameter is vertical, and they have an outer and an inner surface and an anterior and a posterior border. The length is conventionally put at from 20–25 mm., the breadth at 15 mm., and the thickness at 10 mm. Practically, however, there is no definite shape nor size. In childhood the tonsil generally projects as a globular mass. If it extends more than slightly beyond the level of the faucial pillars, it is said to be enlarged. After middle life it rises usually but little from the floor of the niche. The shape of the free surface gives no clue to the size of the deep surface. In structure the tonsil is a mass of adenoid tissue enclosed in a fibrous capsule which is crossed on both the deep and free surfaces by a thin layer of muscular fibres. The superficial layer belongs to the palato-glossus ; the deep or external layer arises from the superior constrictor and passes to the tongue. Beyond this externally are fat and areolar tissue. The closely adherent mucous membrane covers the free surface, which is full of pits from 1 or 2 mm. to 1 cm. in depth. The larger ones often expand below the orifice, so that they may collect and retain secretions. A small free space, the *supratonsillar fossa*, lies above the tonsil at the apex of the niche containing it ; at the front of this there is very often a series of crypts with detached adenoid tissue about them, burrowing under the anterior pillar from behind and making a pouch beneath a fold, the *plica triangularis.* The adenoid tissue is continuous below with that of the tongue. The mucous membrane of the oro-pharynx shows many scattered lymphoid follicles in its walls, especially on the sides at and above the level of the tonsils.

FIG. 1355.

Section through faucial tonsil, showing general disposition of lymphoid tissue. × 20.

FIG. 1356.

Portion of faucial tonsil, showing epithelial lining of crypt invaded by escaping lymphocytes. × 325.

Vessels.—The *arteries* supplying the faucial tonsil are derived from several sources, and the arrangement of the vessels is extremely irregular ; the branch from the ascending pharyngeal and that from the facial artery—one or both—enter its base, while twigs from the lingual and descending palatine arteries,

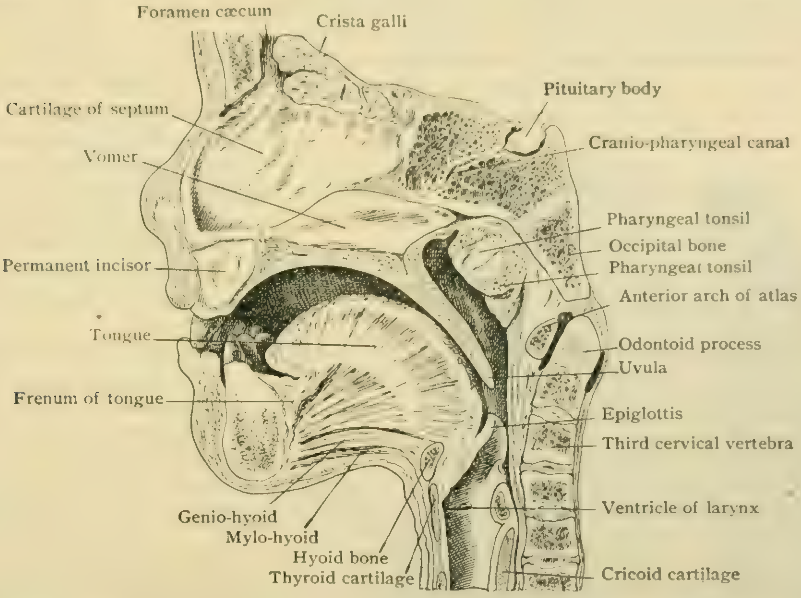
and perhaps others, reach it beneath the mucous membrane. Under ordinary circumstances the tonsil is not very vascular, but receives a large quantity of blood when inflamed. There is a *venous plexus* communicating with the veins of the pharynx. The *lymphatics* probably communicate both with those of the dorsum of the tongue and with the glands near the angle of the jaw.

Nerves.—The nervous supply is from the fifth and the glosso-pharyngeal.

(The relations of the tonsils are given with those of the pharynx, page 1602.)

The **pharyngeal tonsil** (Fig. 1353), sometimes called the *third tonsil*, is a median mass of adenoid tissue in the postero-superior wall of the pharynx, which reaches its greatest development in early childhood, generally dwindling after the twelfth year. When well developed, it lies below the occipital and the basi-sphenoid, nearly filling the space from the nasal septum to the back of the pharynx and almost touching on either side the folds made by the tubal cartilages. Its thickness in the median line is nearly 1 cm. Thus without being hypertrophied it nearly fills the naso-pharynx. The pharyngeal tonsil is a lobulated organ, the swellings being often regu-

FIG. 1357.



Anterior portion of mesial sagittal section of child's head, probably of about three years. Reduced one-fourth.

larly arranged around a *central depression;* consequently it presents many pockets. The central one, which varies widely, is often improperly called the bursa pharyngea. It has absolutely nothing to do with the canal from the mouth to the sella turcica, through which a process of the oral tissue passes in early fœtal life to the pituitary body (Fig. 1357), being decidedly behind that passage. Neither is it the true *bursa pharyngea*, since this term is more properly applied to a structure of uncommon occurrence,—namely, a still more posterior pocket in the mucous membrane leading from the roof of the pharynx, just behind its tonsil, into a small recess not over 1.5 cm. in length, on the under side of the basilar process.

Relations of the Pharynx.—The structures behind the posterior wall have been mentioned (page 1596). The tip of the normal uvula hangs on a level near the lower part of the axis or the top of the third cervical vertebra. The tip of the epiglottis is usually opposite the lower part of the third. The second and third cervical vertebræ are those behind that part of the pharynx seen through the open mouth. The pharynx ends at about the top of the seventh cervical vertebra. The lateral wall of the pharynx is very narrow, except in the region of the tonsils, where it reaches forward to the anterior pillar of the fauces. From the top of the thyroid downward it

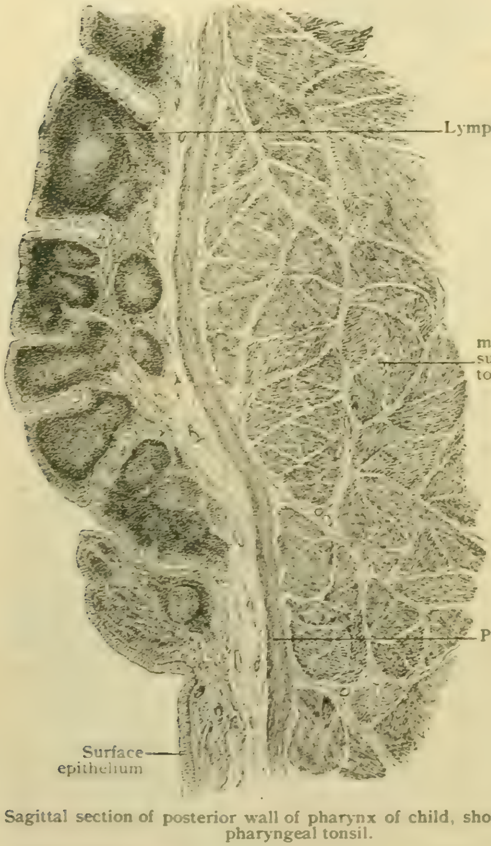
is nothing more than the fold around the end of a transverse linear cleft. The whole lateral aspect is covered by a thick layer of areolar tissue, continuous with that of the carotid sheath. It is most convenient to give the relations of the lateral wall from below upward, excepting the nerves. The upper part of the lobes of the thyroid gland comes very close to the lower part of the pharynx, and may even touch it without undue enlargement. They separate the common carotid from the pharynx. A little higher this vessel is on the outer side of the great wing of the thyroid cartilage, but if the head be turned to one side the vessel of the other side will rest on the pharynx. The common carotid artery is very close to the pharynx just before its division. The internal carotid lies against it until it reaches the skull. The beginning of the external carotid with its lingual and facial branches is also against it. The ascending pharyngeal artery runs along it, the middle meningeal lying against its upper part. The internal jugular vein is, probably, nowhere in direct contact with the pharynx unless just below the skull. The submaxillary gland touches it at the angle of the jaw.

FIG. 1358.

Pharyngeal tonsil of child one year old. (*Schwabach.*)

The sympathetic nerve comes in contact with the back or side of the pharynx. The vagus lies against the pharynx behind the internal carotid; on reaching the common carotid, however, it is in less direct contact. Its superior laryngeal branch crosses the pharynx to reach the thyro-hyoid membrane. The spinal accessory and the glosso-pharyngeal nerves lie against the upper part of the pharynx.

FIG. 1359.



Sagittal section of posterior wall of pharynx of child, showing part of pharyngeal tonsil.

The **faucial tonsil** lies about 2.5 cm. above the angle and opposite a vertical line dividing the ramus of the jaw into a front and a back half. It lies between the pillars of the fauces, and is separated from the mucous membrane by a thin layer of muscular fibres. The lower end reaches the tongue, the adenoid tissue being at times continuous between them. The tonsil is covered by the superior constrictor. External to this is a yielding mass of areolar tissue, continuous with that of the carotid sheath, into which the tonsil may force its way if enlarged. This areolar tissue is bounded in front by the internal pterygoid muscle, and is pierced by the stylo-glossus and the stylo-pharyngeus, which subdivide it, leaving a small part of it between them and the tonsil. At this level both carotids are at a considerable distance from the tonsil. The internal is posterior and external, about 2 cm. distant. According to Zuckerkandl, a transverse line through the posterior pillar will pass

2 cm. in front of the vessel. The external carotid is placed more directly outward and is rather the nearer of the two. The parotid gland, according to Tillaux, sends a process in front of the styloid process, which reaches the lateral wall. This extension, however, does not seem to be by any means constant.

Development and Growth of the Pharynx.—An account of the formation of the primitive pharynx is included in the Development of the Alimentary Tract (page 1694), the later changes being here noted. In the section on the bones it was shown that the chief peculiarities of the infant skeleton in this region are due to the small size of the face and the more horizontal base of the skull. The naso-pharynx has very little height while, owing to the peculiar disposition of the parts, it has nearly the same antero-posterior diameter as in the adult. It is relatively broad and long, but very shallow. The tongue, in proportion, is much less thick at the base than later. The larynx is small, and, moreover, is placed higher in relation to the vertebral column, so that the termination of the pharynx is also higher. The position of the larynx at different ages is considered with that organ (page 1828). The soft palate is in the main horizontal at birth and about on a level with the top of the atlas. The uvula is rudimentary. In a child of probably not over three years we have found the tip of the uvula rather below the middle of the body of the axis. In Symington's section of a girl of thirteen it is pretty nearly in the adult position. In infancy the soft palate probably closes the passage into the naso-pharynx from below less perfectly than later.

The *opening of the Eustachian tube*, although necessarily in the naso-pharynx, is in the fœtus below the level of the hard palate. At birth it is at about that level, but rather below than above it. According to Disse, there is but little change for nine months, after which the opening is on the level of the inferior meatus. Probably the adult position is generally reached after puberty. The opening is small in the infant and young child, and, owing to want of development of the cartilage, there is but a slight elevation about it and consequently but a small fossa of Rosenmüller. The entire adenoid system of this region[1] has made but little progress before birth.

At birth the *pharyngeal tonsil* is a very small collection of adenoid tissue at the back of the roof, covered by more or less converging folds of the mucous membrane. It is not necessarily present. During the first year it grows rapidly, and particularly forward, so that by the end of that time it extends to the back of the upper margin of the choanæ. Under normal conditions the pharyngeal tonsil retains its relative size to the cavity of the pharynx up to twelve years; but during this time the total amount of adenoid tissue has decidedly increased, owing to the development of the tubal tonsils.

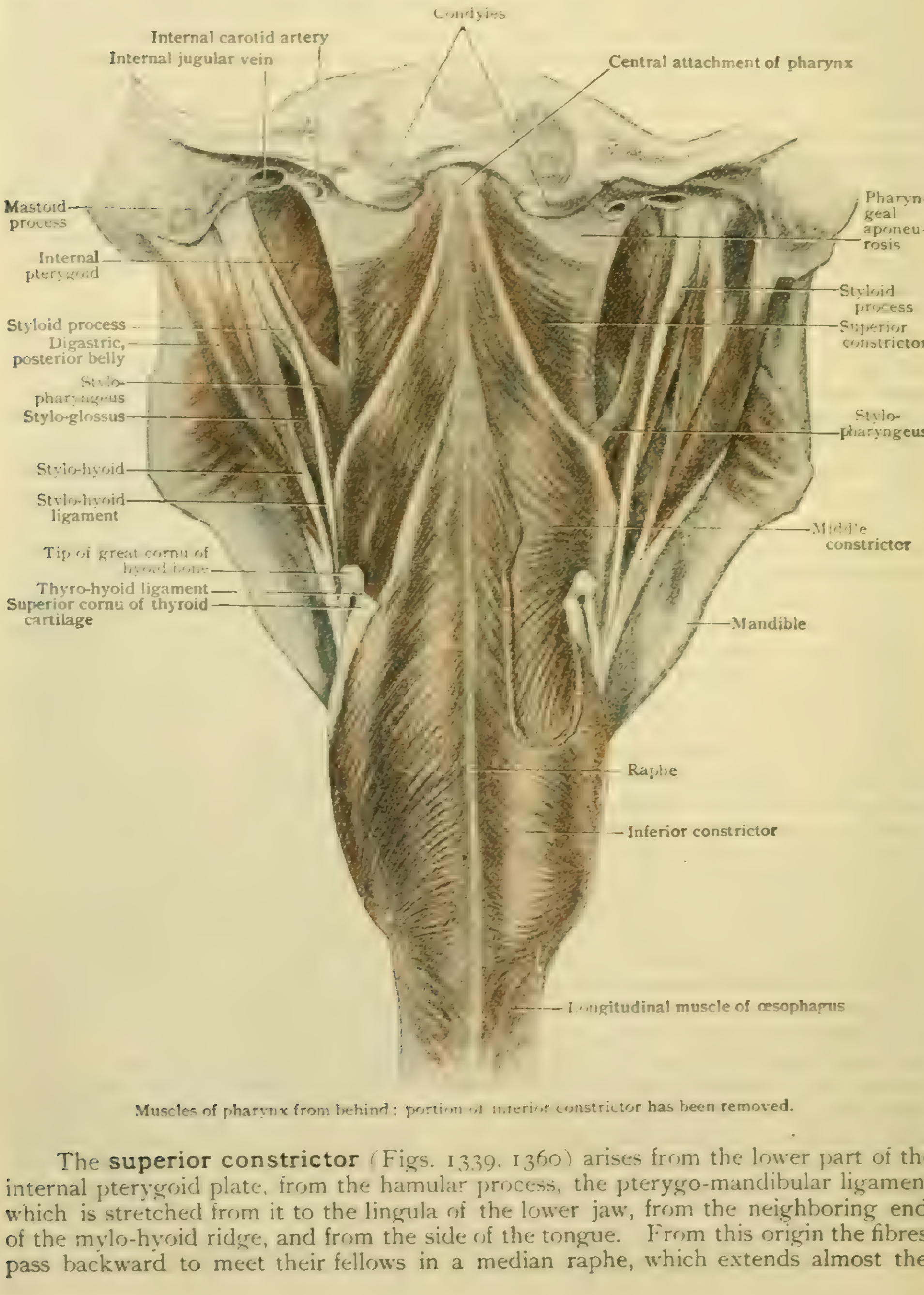
The *faucial tonsils* are developed in a recess of the primitive pharynx between the second and third visceral arches. By the fourth fœtal month the tonsillar anlage presents a number of slit-like depressions, lined with entoblastic epithelium, from which secondary epithelial sprouts invade the neighboring mesoblast. This process continues after birth during the first year. The young connective tissue surrounding the epithelial sprouts—the latter being at first solid, but later possessing a lumen—becomes infiltrated by accumulating leucocytes and gradually assumes the character of adenoid tissue, the differentiation into distinct lymph-nodes, however, being delayed until after birth. The source of the lymphoid cells is a matter of dispute. According to some, these elements are leucocytes from the circulation caught within the young connective tissue; others maintain that they are derived from the transformation of the epithelium, the lymphoid tissue resulting from the mutual invasion and intergrowth between the ento- and mesoblastic elements. According to Hammar,[2] who has carefully studied the development of the tonsils, the lymphoid cells are derived chiefly from the fixed connective-tissue elements. At birth the tonsils are insignificant, but grow rapidly during the first year. At from the twelfth year to puberty the entire adenoid system of the pharynx enters upon a stage of retrogression. In the adult the pharyngeal and tubal tonsils are much smaller; after middle age they undergo atrophy.

[1] Escat: Évolution de la Cavité Naso-Pharyngienne, 1894.
[2] Archiv f. mikro. Anat., Bd. xli., 1902.

THE MUSCLES OF THE PHARYNX.

The arrangement of the muscular tissue differs from the ordinary one of the digestive tract, inasmuch as the outer layer is approximately circular and the longitudinal fibres are largely internal. The chief elements are the three *constrictors*, which overlap one another from below upward, the *stylo-pharyngeus*, the *palato-pharyngeus*, and certain accessory and rather irregular bundles of muscular fibres.

FIG. 1360.

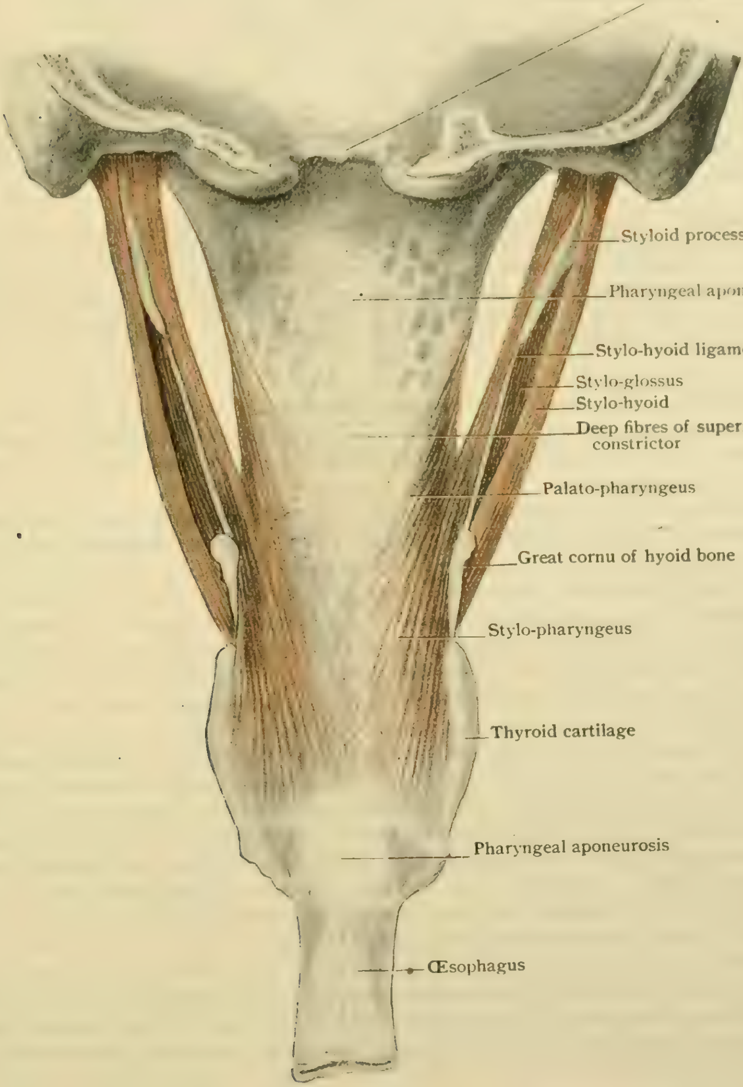


Muscles of pharynx from behind: portion of inferior constrictor has been removed.

The **superior constrictor** (Figs. 1339, 1360) arises from the lower part of the internal pterygoid plate, from the hamular process, the pterygo-mandibular ligament which is stretched from it to the lingula of the lower jaw, from the neighboring end of the mylo-hyoid ridge, and from the side of the tongue. From this origin the fibres pass backward to meet their fellows in a median raphe, which extends almost the

entire length of the posterior wall of the pharynx, being attached above to the pharyngeal tubercle on the under side of the basilar process. The upper edge of the muscle is concave on either side, not reaching the base of the skull and passing under the Eustachian tube, the vacant space being filled by the pharyngeal aponeurosis. The lower fibres pass somewhat downward as well as backward. The pterygomandibular ligament separates the superior constrictor from the buccinator, with which it would otherwise be continuous, forming a circle around the alimentary canal.

FIG. 1361



Pharyngeal aponeurosis and longitudinal musculature, seen from behind.

The **middle constrictor** (Figs. 1339, 1360) arises from the lower end of the stylo-hyoid ligament, from the lesser horn of the hyoid bone, and from the upper border of the greater horn. The fibres diverge from this narrow origin, the upper reaching the pharyngeal tubercle, the lower going to nearly the lower end of the pharynx, and all meeting their fellows in the median raphe. It conceals a considerable part of the preceding muscle.

The **inferior constrictor** (Figs. 1339, 1360), the thickest of the three, arises from the posterior part of the outer aspect of the cricoid cartilage, from the oblique line and the triangular surface below and behind it on the thyroid cartilage, including the inferior horn. It overlaps the preceding muscle, its upper fibres reaching to some 3 cm. below the base of the skull and the lower ones being nearly horizontal. The median raphe, which receives almost all the fibres, is wanting below. The lowest fibres are circular and continuous with the circular fibres of the gullet.

The **stylo-pharyngeus** (Fig. 1361) arises from the inner side of the styloid process near its root and descends to the interval between the superior and middle constrictors near the hyoid bone, where it passes under the latter and ends by expanding in the side of the pharynx, some of its fibres going to the posterior border of the thyroid cartilage and others joining the expansion of the palato-pharyngeus. A bundle from the thyroid division passes to the side of the epiglottis, forming on the wall of the pharynx the fold known as the *plica pharyngo-epiglottica*. The fibres of the superior constrictor may be inseparable from the upper part of this layer.

The **salpingo-pharyngeus** has been described in connection with the levator palati (page 1571).

Variations.—Additional muscles are very common, being chiefly longitudinal bundles due to splitting of one of the normal muscles, especially the stylo-pharyngeus, or to new bundles of fibres arising from the base of the skull in the vicinity of the upper insertion of the pharyngeal fascia. There may be a pair of *occipito-pharyngeal muscles*, arising from the occipital bone on either side of the median line and descending to be lost in the posterior pharyngeal wall; or there may be an *azygos muscle* instead. Bands may arise at the side from the petrous portion of the temporal bone or the spine of the sphenoid.

Actions.—The general action of the pharyngeal muscles is sufficiently evident; the constrictors decrease the size of the pharynx, probably drawing the larynx upward and backward at the same time. The longitudinal muscles raise the larynx and pharynx, acting chiefly on the latter.

Vessels.—The *arteries* of the pharynx are from many sources and are irregular. The chief is the ascending pharyngeal, which runs up near the posterior lateral angle. Occasionally, when enlarged, it is seen pulsating on the posterior wall. Branches from the facial play an uncertain part. The *veins* form the pharyngeal plexus situated outside of the constrictors and communicating in all directions. The chief outlets are by a pair of veins on each side, one going up to the internal jugular near the base of the skull and the other down to the external jugular or some of its tributaries (Luschka). A submucous plexus is particularly developed in the lower posterior wall, which opens into the pharyngeal plexus by several branches piercing the inferior constrictor. The following are nearly constant: a superior and posterior one near the middle line, one running outward on each side near the back of the thyroid cartilage, forming a part of the origin of the pharyngeal vein, and one passing forward to the superior thyroid vein.[1] The *lymphatics*, which are numerous, run in the upper part to the prevertebral nodes and to the deep cervical system, as do the lower ones at another level. The presence of lymphatic nodes behind the naso-pharynx is of practical importance, as they are sometimes inflamed and may suppurate. They lie near the fossæ of Rosenmüller.

Nerves.—The constrictors are supplied by the pharyngeal plexus, the lower receiving fibres also from the recurrent laryngeal. The stylo-pharyngeus is supplied by the glosso-pharyngeal. The nerves of the mucous membrane are from the glosso-pharyngeal, the pneumogastric, and the sympathetic, to a great extent in a plexiform arrangement.

PRACTICAL CONSIDERATIONS: THE PHARYNX.

The pharynx may be said to present only three sides for consideration, but its continuity above with the nares, anteriorly with the mouth, and below with the orifices of the larynx and œsophagus associates it intimately with the diseases of those regions. The naso-pharynx and the laryngeal relations will be considered with the Respiratory Passages (page 1829).

[1] Bimar et Lapeyre: Comptes rendus de l'Acad. des Sciences, Paris, tome cv., 1887.

The *posterior wall* of the pharynx is separated from the anterior surfaces of the bodies of the first five cervical vertebræ only by some loose connective tissue and by the prevertebral fascia and muscles. Through it, by pushing the finger up above the soft palate, the basilar process of the occipital bone may be felt, and below the bodies of the upper four cervical vertebræ—in children the upper six—may be palpated. The hard palate, or the lower margin of the posterior nares, and the anterior arch of the atlas are on the same level.

In disease of the body of the sphenoid, in fracture of the base of the skull involving the basilar process, or in fracture or dislocation of the cervical vertebræ the information gained by this examination will often be of great value.

The retropharyngeal alveolar tissue—which is necessarily loose to permit of the movements of the pharynx during deglutition and of its distensibility—is sometimes the seat of infection which may have gained access through the pharynx itself, or through the lymphatics which spring from the posterior nares, the summit of the pharynx and the prevertebral muscles, and which empty into a lymph-gland situated between the prevertebral fascia and the pharyngeal wall. Abscess in this situation may by gravity descend by the side of the œsophagus into the mediastinum and has been known to reach the base of the thorax (page 553, Fig. 546). During its descent it may cause much dyspnœa by setting up œdema in the region of the glottis. Usually it first pushes forward the posterior wall of the pharynx, and can be recognized as a fluctuating swelling and opened by direct incision.

Collections of fluid resulting from tuberculous disease of the cervical vertebræ may occupy the same space after perforating the thin prevertebral fascia and may take the same course, or they may be guided by the lateral expansions of that fascia to the posterior and lateral portions of the root of the neck or to the axilla (page 552, Fig. 545). As in these cases the avoidance of mixed infection is very important, such tuberculous collections, when they require opening, should be approached through the neck by an incision along the posterior border of the sterno-mastoid.

Retropharyngeal abscess of any type should never be allowed to open spontaneously on account of the danger of immediate suffocation from flooding of the larynx with pus.

In cases of fracture of the posterior fossa of the base of the skull, with hemorrhage into the pharynx (fracture of the basilar process), or of the middle fossa, with hemorrhage reaching the pharynx through the Eustachian tube (fracture of the petrous portion of the temporal), the need for frequent and persistent attempts to make and keep the pharynx as nearly aseptic as possible should never be forgotten.

The adenoid tissue of the posterior wall—the pharyngeal tonsil—may undergo hypertrophy, cause deafness or respiratory obstruction, and require removal.

The *lateral walls* of the pharynx are in such close relation with the internal carotid artery that in aneurism of that vessel the pulsations may most easily be felt and seen through the pharynx. In many instances the vessel has been opened in penetrating wounds of the pharyngeal wall by foreign bodies. The internal jugular vein is not so exposed to injury and is more rarely wounded. In one instance of pulsating tumor of the pharynx, pressure on the external carotid arrested the pulsations (Barnes).

The styloid process and a rigid or ossified stylo-hyoid ligament can be felt through the lateral wall. Attempts have been made (in cases of hysterical persistence of pharyngeal symptoms after the supposed swallowing of a foreign body) to remove these structures or a cornu of the hyoid bone, under the impression that they were the offending substances.

The pharynx is very distensible, and foreign bodies, if not of great size, are apt to pass through it as far as the level of the cricoid cartilage, where its diameter is only 18 mm. (¾ in.). In an adult this point is beyond the reach of an average finger, as it is about the entrance of the œsophagus, which is about six inches from the incisor teeth.

For the removal of impacted foreign bodies, or for operation on malignant disease, the pharynx may be reached, after a preliminary tracheotomy, by an incision

through the neck from a point midway between the symphysis and the angle of the jaw to the cricoid cartilage, dividing the platysma and the omo-hyoid and separating the posterior belly of the digastric and the stylo-hyoid from the hyoid bone; or a subhyoid pharyngotomy will give access to the lower walls of the pharynx by division of the superficial fascia, the sterno-hyoid and thyroid muscles, the thyro-hyoid ligament and membrane, and the mucous membrane of the pharynx at the level of the lower margin of the hyoid bone. These operations are more interesting anatomically than surgically.

The **tonsils**, as seen from the mouth, are situated between the arches of the palate and the base of the tongue. They may be almost concealed in these recesses or may project into the pharynx, and when hypertrophied may actually meet in the middle line. They rest on the superior constrictor muscles and move with those muscles during the act of deglutition. They are somewhat elevated and withdrawn from the pharynx by the coincident contraction of the stylo-pharyngei. Swallowing is therefore apt to be painful in all forms of tonsillitis. If not enlarged, they are often almost hidden in persons who have large palato-glossi muscles, and therefore prominent anterior palatal arches. Externally they are separated by the pharyngeal aponeurosis and the superior constrictor muscle from the pharyngo-maxillary space. This space is bounded by these fibro-muscular structures internally, the internal pterygoid muscle externally, and the antero-lateral aspects of the bodies of the second and third cervical vertebræ. It is occupied by some connective tissue and fat. According to Zuckerkandl, the stylo-pharyngeus and stylo-glossus muscles divide the space into an anterior portion in relation to the tonsil and a posterior in relation to the internal carotid artery and internal jugular vein.

Tonsillitis in the lacunar or follicular form does not usually involve the stroma of the gland, the infection and the exudate being limited to the tonsillar crypts and to the surface. In the suppurative form the infection is deeper, the stroma is affected, and the resulting abscess may in rare cases become peritonsillar, extend to the cellular tissue of the pharyngo-maxillary space, and open the internal carotid artery. Usually, as the infection progresses, even if this space is invaded, the outward extension is limited by the internal pterygoid muscle, and the swelling and the ulceration or necrosis take the line of least resistance,—*i.e.*, towards the pharynx, where tonsillar abscesses often open spontaneously.

During an acute tonsillitis the palato-glossus and its covering of mucous membrane, with the soft palate on the affected side, are tense, thinned, and spread out over the surface of the tonsil. Abscesses may be evacuated by incision directly through these structures and from above downward in a direction parallel with the anterior pillar,—that is, with the fibres of the palato-glossus.

The vascular relations of the tonsil should be remembered in this operation or in tonsillotomy for hypertrophy. The internal carotid is nearly 2.5 cm. (1 in.) behind and to the outer side of the tonsil. The external carotid is still farther removed, as it lies outside of the stylo-glossus and stylo-pharyngeus muscles. Its ascending pharyngeal branch is nearer the tonsil than either of the main trunks, and in a case of accidental wounding by a foreign body has been the source of fatal hemorrhage. Wounding of the tonsillar branch of the facial artery has likewise proved fatal after tonsillotomy, and either this vessel or the facial itself, especially if it is tortuous where it passes between the stylo-glossus and digastric muscles, is probably involved in cases of grave hemorrhage after this operation. The plexus of lymphatics surrounding the follicles of the tonsils communicates directly with the deep cervical lymph-glands behind and beneath the angle of the jaw. These glands are therefore commonly enlarged in affections of the tonsils, and when tender and palpable are sometimes mistaken for the tonsils themselves. The latter cannot, however, be palpated externally, except in cases of new growth, as the resistance offered by the constrictor, the internal pterygoid, and other structures intervening between the tonsils and the skin causes them to project towards the pharynx. This projection may be a cause of various forms of ill health associated with deficient oxygenation, of chronic pharyngitis from mouth-breathing, of thickened articulation and even of alterations in the facies or in the skeleton,—*e.g.*, "pigeon-breast" (page 167).

The deafness often associated with hypertrophied tonsils is the result of adenoid growth in and about the Eustachian tube. The intervention of the soft palate prevents direct pressure by the enlarged tonsil upon that canal. Reflex spasmodic cough may follow irritation of the glosso-pharyngeal filaments by inspissated secretion within the follicles; fetid breath often results from the decomposition of such secretion; epithelial necrosis and denudation render such tonsils a common seat of entrance of various infections, as the tuberculous—emphasized by the frequency with which the cervical glands just mentioned are the first to enlarge in tuberculous adenitis of the neck—or those streptococcic or staphylococcic varieties in which acute arthritis (including many cases of so-called "inflammatory rheumatism") or endocarditis may follow a trifling "sore throat."

THE ŒSOPHAGUS.

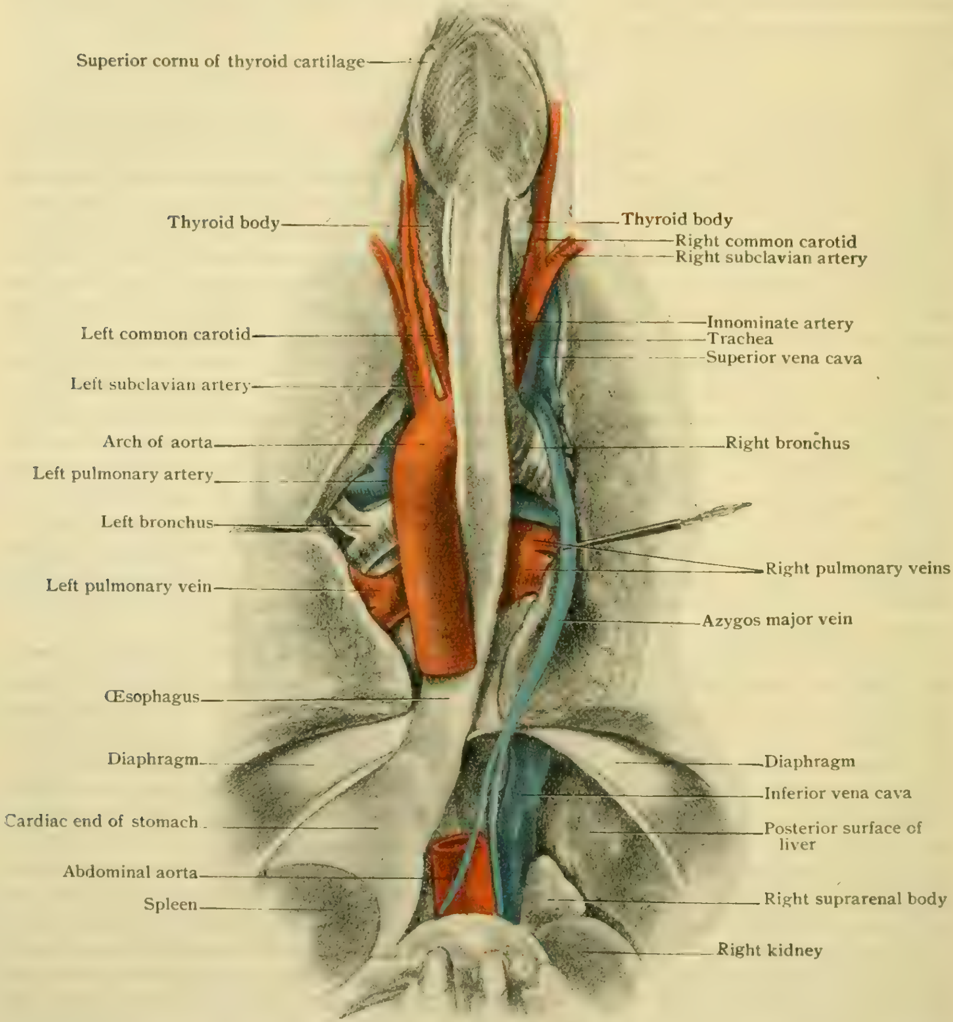
The œsophagus or gullet is a musculo-membranous tube, about 25 cm. (10 in.) in length, connecting the pharynx and the stomach. It begins at the lower border of the cricoid cartilage near the disk between the sixth and seventh cervical vertebræ, about 15 cm. from the incisor teeth, and ends below the diaphragm, opposite the tenth (sometimes the eleventh) thoracic vertebra. The entrance into the stomach is marked by a groove on the left of the gullet, best seen when the organs are inflated. There is no line of separation on the right when the parts are unopened. The form and calibre of the œsophagus are very variable and uncertain. Longitudinal folds are sometimes found, especially in the upper part, which give the cavity a star-shaped appearance on transverse section. Often the front wall lies in contact with the back one; at the lower part, however, there may be a permanent cavity. Constrictions have been described very variously. Probably the most marked occurs at the very beginning, with a diameter of perhaps only 14 mm. There is usually one at the passage through the diaphragm, often one at the point where the arch of the aorta crosses the gullet, and another where the latter goes behind the origin of the left bronchus. Mehnert[1] has described thirteen places, at any one of which there may be a constriction. They correspond to the points of entrance of the arteries, and, according to him, have a metameric significance. Occasionally the œsophagus is much dilated, the diameter exceeding 3 cm. It is probably constricted in life. After passing through the diaphragm it presents a funnel-like expansion.

Course and Relations.—Throughout its course the gullet is surrounded by much areolar tissue and frequently sends fibres from its muscular coat to neighboring parts. While following the general direction of the vertebral column, although not closely, below the bifurcation of the trachea the gullet lies 1 or 2 cm. in front of the spine. Directly after its beginning it inclines to the left, so that soon it projects by one-half beyond the left border of the trachea. We have seen, in a child, the two tubes lie side by side. Just above the bifurcation of the trachea the œsophagus meets the arch of the aorta, which, so to speak, pushes it to the right; it lies, however, always behind the beginning of the left bronchus, while to a less degree, or even not at all, it is in relation to the right one. Owing to the influence of the aorta, the gullet passes farther to the right; but, leaving the spine, it lies behind the pericardium in a plane somewhat anterior to that of the aorta, and near the diaphragm sweeps in front of the aorta to the left of the median line, passes into the abdomen near the lower border of the tenth thoracic vertebra, and, running very obliquely, presently ends in the stomach. Hardly more than 1 cm., which lies behind the left lobe of the liver and in front of the left pillar of the diaphragm, can be said to be subdiaphragmatic, when examined from without. The line of separation between the œsophagus and the stomach, however, is very clear on the inner surface, owing to the sudden change in the nature of the epithelial lining. There is often a fold on the left of the end of the gullet, usually at the upper and back part, from 2–5 mm. broad,[2] which, perhaps, acts as a valve against regurgitation. The subdiaphragmatic part is about 3 cm. long. Sometimes the longitudinal folds of the gullet seem to project into the stomach, but usually it ends in a gradual expansion.

[1] Verhandlung. der Anat. Gesellschaft, 1898.
[2] Berry and Crawford: Journal of Anatomy and Physiology, vol. xxxiv., 1900.

At first the œsophagus lies behind the trachea on the prevertebral fascia, the lobes of the thyroid gland touching it on either side. As it descends to the left, the trachea is partly on the right. The left recurrent laryngeal nerve runs on the front. The right one is in relation with only the very beginning of the gullet. The right inferior thyroid artery is against it. On the right also a chain of lymphatics in the areolar tissue lies very close to it. The left carotid and subclavian arteries are very near it, if not in actual contact. As may be inferred, the gullet and the aorta are

FIG. 1362.



Œsophagus and related structures, seen from behind. Lungs have been pulled aside and posterior part of diaphragm removed.

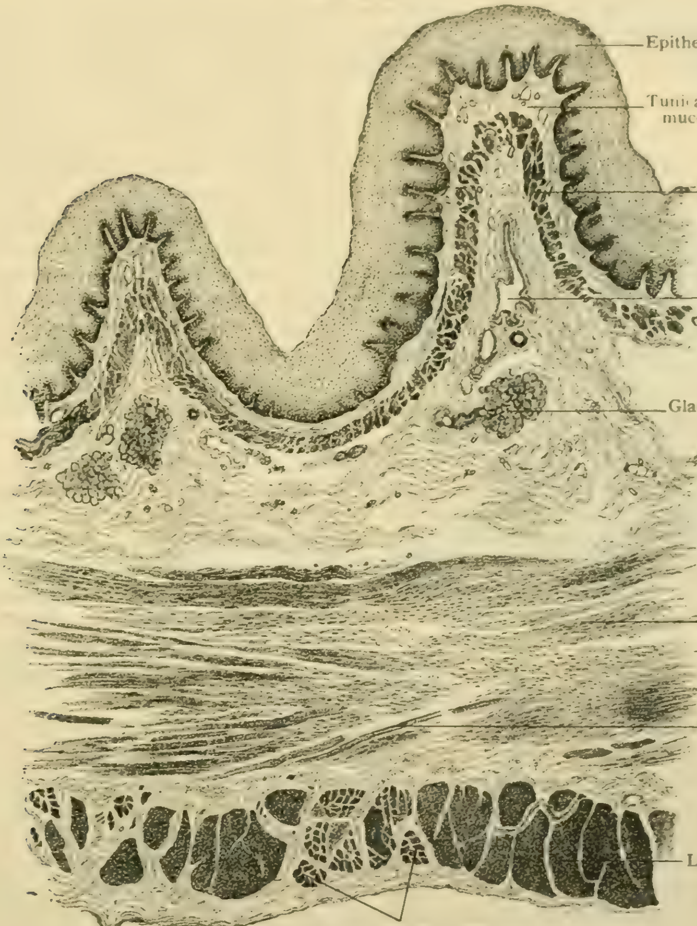
spirally entwined. The thoracic duct and the vena azygos major are in contact with it from the diaphragm to above the roots of the lungs, the former lying between it and the aorta as far as the level of the aortic arch, the latter, at first more posterior than the duct, passing as it rises behind the œsophagus and finally arching forward close to its right side. The left vena azygos, such left intercostal veins as open into the azygos major, and the right intercostal arteries pass behind the gullet. The pneumogastrics reach it in the thorax : the right after crossing the subclavian artery and

the left after crossing the aorta. The nerves then break up into plexuses, from which they emerge near the diaphragm, the left in front, the right behind the food tube. On entering the thorax, the œsophagus is in contact with the left pleura, and continues to be until separated from it by the aorta. Behind the pericardium it is in contact with the right pleura, and just before passing through the diaphragm it is in contact with both.

Muscular fibres bind the œsophagus to various neighboring structures. A tolerably constant band attaches it to the left bronchus, and others may go obliquely to the right bronchus. Several irregular bands, mostly muscular, pass from it to various parts of the pleuræ and pericardium.

Structure.—The wall of the œsophagus (3.5–4 mm. thick) consists of four

FIG. 1363.



Transverse section of œsophagus, junction of middle with upper third. × 25.

layers, which, from within outward, are the mucous, the submucous, the muscular, and the fibrous coats.

The *mucous coat*, usually thrown into longitudinal folds, is composed of a tunica propria formed of fibrous connective tissue and delicate elastica and covered with stratified squamous epithelium. Beneath the latter the surface of the stroma-layer presents longitudinal ridges and papillæ, between which pass the ducts of the glands in their course to the free surface. The deeper part of this layer is occupied by a *muscularis mucosæ*, the involuntary muscle of which begins at the cricoid cartilage, first

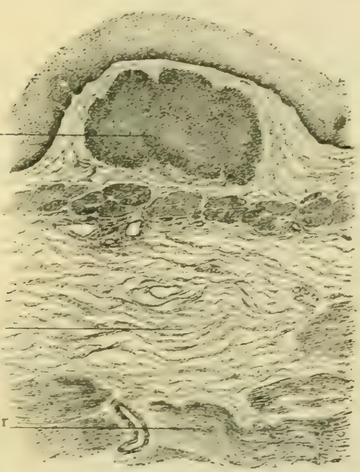
appearing in the continuation of the elastic lamina of the pharynx. At the upper end only slightly developed, the muscularis mucosæ becomes more robust until in the lower portion of the œsophagus it is conspicuous.

The *submucous coat*, between the mucous and muscular layers, although considerable, is not dense, and therefore allows free motion of the former upon the latter, as well as the formation and effacement of folds. It is continuous with the pharyngeal fascia above.

The *œsophageal glands* are of two kinds,—the ordinary mucous, situated within the submucous coat and scattered throughout the length of the tube, and special glands within the tunica propria limited to the two ends of the œsophagus. The last mentioned correspond in structure to those found at the cardiac orifice of the stomach; they are therefore known as the upper and lower *cardiac œsophageal glands* (J. Schaffer).

The usual secretory structures are small tubo-alveolar mucous glands in which mucus-producing cells are alone present, crescents of serous elements being absent. The ducts are commonly somewhat tortuous, and often present dilatations or ampullæ; the smaller tubes are clothed with simple columnar epithelium. In the larger the epithelium may be stratified, and near the free surface assume a squamous character.

FIG. 1364.



Section of mucous membrane of œsophagus, showing lymph-node. × 55.

The cardiac glands at the lower end of the œsophagus are continuations of those situated about the entrance of the gullet into the stomach, in connection with which organ they are more fully described (page 1624). They form oval or pyramidal groups of branched tubular glands, the bases of which lie against the muscularis mucosæ, the narrow parts being directed towards the free surface onto which their wavy or tortuous ducts open. The upper cardiac glands form, according to Schaffer,[1] a constant, though variable, group around the superior end of the œsophagus.

Lymphatic tissue occurs within the mucosa of the œsophagus as more or less distinct aggregations. Sometimes these are in the form of small diffuse areas of infiltration around the ducts of the mucous glands; in other places, especially towards the lower end, distinct lymph-nodules are present (Fig. 1364).

The *muscular coat* consists of an inner circular and an outer longitudinal layer, although the disposition of the individual bundles is often irregular and oblique, and above somewhat intermingled. In the upper one-fifth of the tube the muscular tissue consists entirely of striped fibres, the circular ones being continuous with the similarly disposed fibres of the inferior constrictor of the pharynx. The longitudinal fibres arise from a tendon attached to the median ridge of the cricoid cartilage and to the fascia covering the posterior crico-arytenoid muscles, whence they descend to embrace the gullet. They are few at the top behind, but lower down the circular and longitudinal layers are distinct and symmetrically disposed. Towards the middle of the œsophagus the muscular coat includes both the striated and non-striated form of tissue, the involuntary variety gradually predominating until in the lower two-fifths it alone is present.

The *fibrous coat* is poorly developed above the diaphragm, consisting of the areolar tissue which connects the gullet to the surrounding structures. After piercing the diaphragm, the peritoneal investment contributes a limited serous tunic which from this point on is well represented.

Vessels.—The *arteries* are links in the chain running the whole length of the alimentary canal. The highest are from the inferior thyroids, succeeded by those

[1] Beiträge zur Histologie mensch. Organe, Bd. vi.

from the thoracic aorta and the gastric. The *veins* are interesting only inasmuch as the upper ones open into the azygos system and that of the inferior thyroid above and the gastric system below; they thus form a communication between the general and the portal venous systems. The *lymphatics*—not numerous—go to the nodes of the deeper part of the neck and of the posterior mediastinum.

Nerves are from the œsophageal plexus.

The mechanism of the closure of the cardiac end of the stomach is most properly considered with the œsophagus, depending as it does partly on the direction of that tube, partly on the relation of the diaphragm to it, and partly on the folds of mucous membrane at its orifice. Frozen sections (Fig. 1509), both horizontal and frontal (Gubaroff[1]), show that the termination is almost horizontal. Dissections of the diaphragm from above demonstrate that the arrangement of the muscular fibres is that of a sphincter, although a weak one. The projection of the folds into the stomach is a further protection. It has been shown that the cardia will resist moderate pressure from below upward, but will yield to considerable force. The action of the longitudinal fibres from both the cricoid cartilage and the diaphragm is to dilate the tube.

PRACTICAL CONSIDERATIONS: THE ŒSOPHAGUS.

Congenital malformations are rare, as yet unexplained embryologically, and usually fatal. The œsophagus may be double, deficient, or absent. Most commonly there are an upper cul-de-sac and a lower segment opening into the stomach, sometimes communicating with the respiratory passage. Cases in which there has been an œsophago-pleuro-cutaneous fistula are possibly associated with this malformation (MacLachlan, Osler). Congenital diverticula are found, and Francis suggests three theories for their occurrence: first, that they might be analogous to the diverticula which were found in some of the Sauropsida and in ruminant animals, forming the first two compartments of the stomach; secondly, that they were fœtal varieties analogous to the œsophageal diverticulum from which the larynx, trachea, and lungs are formed; and thirdly, that they resulted from a failure in the internal closure of a branchial cleft (Maylard).

The curves, distensibility, and constrictions of the normal œsophagus and its relations to surrounding structures are of importance with reference to foreign bodies, to stricture, to disease of the gullet with possible extension to neighboring organs, or to extrinsic disease involving the œsophagus either by mechanical pressure or traction or by extension to its walls.

Foreign bodies, if moderately smooth or regular in shape, are apt to be arrested at one of the three relatively constricted portions,—*i.e.* (1), and most commonly, at the commencement, 15 cm. (6 in.) from the incisor teeth, which (with the head midway between flexion and extension) is opposite the lower edge of the cricoid cartilage and the sixth cervical vertebra. At this point its average diameter is 14 mm. (approximately ½ in.); foreign bodies arrested here are really in the lower pharynx. (2) At the point, about 10 cm. (4 in.) lower, where the left bronchus crosses the œsophagus and where the lumen is again lessened by pressure (the distance occupied by the left bronchus in crossing the œsophagus is about 2.5 cm.). (3) At the diaphragmatic opening, where the diameter is once more reduced to 14 mm. by the constriction of the muscular and tendinous fibres surrounding the opening. This point is about 12.5 cm. (5 in.) below the level of the left bronchus, and therefore, approximately, 38 cm. (15 in.) from the incisor teeth. The majority of foreign bodies that pass completely from the pharynx and are arrested in the œsophagus are stopped at or about the level of the left bronchus. Many of them can be extracted through the mouth by suitable instruments; others require an œsophagotomy, which may be done through an incision along the anterior border of the left sterno-mastoid muscle from the cricoid cartilage to the sternum. The longitudinal fibres of the œsophagus will be recognized a little to the left of the trachea, at the bottom of the space between the sterno-thyroid muscle and the common carotid artery. An œsophageal bougie passed through the mouth will aid in the recognition of the tube.

[1] Arch. für Anat. und Phys., Anat. Abtheil., 1885.

The recurrent laryngeal nerve lying in the groove between the trachea and œsophagus should be avoided, as should the superior and inferior thyroid arteries which run across the deeper part of the wound.

With the additional help of a gastrotomy, digital exploration (with perhaps the disengagement of impacted foreign bodies) is possible throughout at least the lower two-thirds of the gullet. If the impaction is near the cardiac end, gastrotomy alone may suffice.

Mediastinal or posterior œsophagotomy has been done on both the left and right sides by resection of three or four ribs (third to eighth), pushing the parietal pleura to one side. The pleura on the left side is more easily displaced than that on the right, which extends across the median line as far as to the right of the thoracic aorta.

Strictures from escharotics or from trauma of foreign bodies may occur at any point, but are, for obvious reasons, most often found at the upper end. Compression of the œsophagus, giving rise to the clinical phenomena of stricture, may be secondary to enlargement of the thyroid body or of the bronchial lymph-glands, to tumors of the mediastinum, to disease of the lower cervical or upper dorsal vertebræ, or to aortic aneurism. The measurement from the incisor teeth to the seat of the narrowing, and comparison with the œsophageal relations at that point, may be of great service in diagnosis.

Carcinoma is the chief disease by which the gullet is attacked. It is found most often at either the upper or lower end of the tube in accordance with its predilection for sites where epithelium changes in character, as at the various mucocutaneous outlets of the body. It is also not infrequent at the region where the left bronchus crosses. It may extend by continuity to the pharynx or stomach or to any of the structures with which the œsophagus is in close contact, or it may spread to the bronchial or mediastinal lymph-glands.

Extrinsic disease may not only (as in the case of tumors or of aneurism) affect the œsophagus by causing compression of its walls (*vide supra*), but may open it by pressure-necrosis or ulceration, or may involve it in the extension of the disease, as in cases of tracheal, bronchial, or pulmonary suppuration or gangrene, or of vertebral caries.

Disease extending from the left lung or pleura to the œsophagus, or in the reverse direction, is more apt to affect the upper portion of the gullet on account of its closer relation to the pleural sac on the left side. Below it is in more intimate relation to the right pleura.

Diverticula of the œsophagus, when acquired, may be due to (*a*) *pressure* from within, as in the region just above a stricture, or oftener on the posterior wall at the pharyngo-œsophageal junction. At this point the inferior constrictor and the circular fibres of the œsophagus—both horizontal in direction—fuse ; it is a point of marked constriction ; the cricoid cartilage in front is movable and non-resistant. In whatever situation found they are apt to be in effect a hernia of the mucous and submucous tissues through the thinned and weakened muscular fibres of the œsophagus or of the inferior constrictor ; or they may be due to (*b*) *traction* from without, as in cases of bronchial lymphadenitis, in which adhesions and subsequent cicatricial contraction have dragged the wall out into a pouch. It is apparent that the anterior wall in the neighborhood of the bifurcation of the trachea and of the left bronchus is most likely to be thus affected.

The recorded cases in which hemorrhage into the œsophagus has taken place from the ascending portion of the aorta, the innominate artery, and the superior vena cava will readily be understood. The relation of the œsophagus just below the aortic arch to the pericardium and left auricle explains the dysphagia sometimes seen in pericardial dropsy or in cardiac enlargement when the patient is supine, as well as the cases in which foreign bodies impacted in the œsophagus have wounded the heart.

In a general way it may be said that the upper or tracheal curve or segment of the œsophagus is most liable to invasion by diseased conditions from without and to obstruction from within, and the lower or aortic curve is relatively free from liability to external pressure or intrinsic occlusion (Allen).

In the use of œsophageal instruments the normal curves, measurements, and constrictions should be remembered, as should the possible relation of abnormal narrowing to abscess, aneurism, or thoracic disease. The curve made by the roof of the mouth, the pharynx, and the beginning of the œsophagus should be somewhat straightened out by throwing the patient's head slightly back ; the tongue and anterior pharyngeal wall should be pulled forward or pushed in that direction by a finger in the pharynx. The point of the instrument should be guided past the epiglottis and brought in contact with the posterior wall of the pharynx before it is pushed downward. This wall—like the upper wall of the urethra—is the more fixed and should guide the instrument safely into the gullet, except in cases of pressure of diverticula. The beginning of the procedure may be facilitated by voluntary deglutition on the part of a non-anæsthetized patient.

In some cases, especially in children, it is preferable to pass the instrument through the nose to avoid the struggle to keep the mouth open.

THE ABDOMINAL CAVITY.

The general shape of the abdominal cavity is best understood by dividing it into three imaginary zones, one above the lumbar region of the spine, one opposite to it, and one below it. The anterior wall is but slightly convex. The upper zone, excepting a small part in front, is within the cage of the thorax, from which it is separated by the dome of the diaphragm, the lower part of which is nearly vertical and posterior to the abdominal viscera. This zone is very capacious. The second zone, bounded behind by the convexity of the lumbar spine, which is broadened on each side by the psoas muscle, is very shallow in the middle, the antero-posterior diameter not being more than 5 cm. (2 in.). At the sides it is deep, extending into the hollow of the lower ribs. Thus it presents two deep lateral recesses connected by a shallow median portion. The lowest zone, below the promontory of the sacrum, consists in the middle of both abdominal cavity proper and of the cavity of the true pelvis ; for, owing to the inclination of the pelvis, the promontory is near the level of the anterior superior spines of the ilia. On each side of this deep median portion the lower zone is bounded behind by the shallow iliac fossæ, rendered yet more so by the ilio-psoas muscles. The deep lateral divisions of the middle zone pass without interruption into these shallow ones.

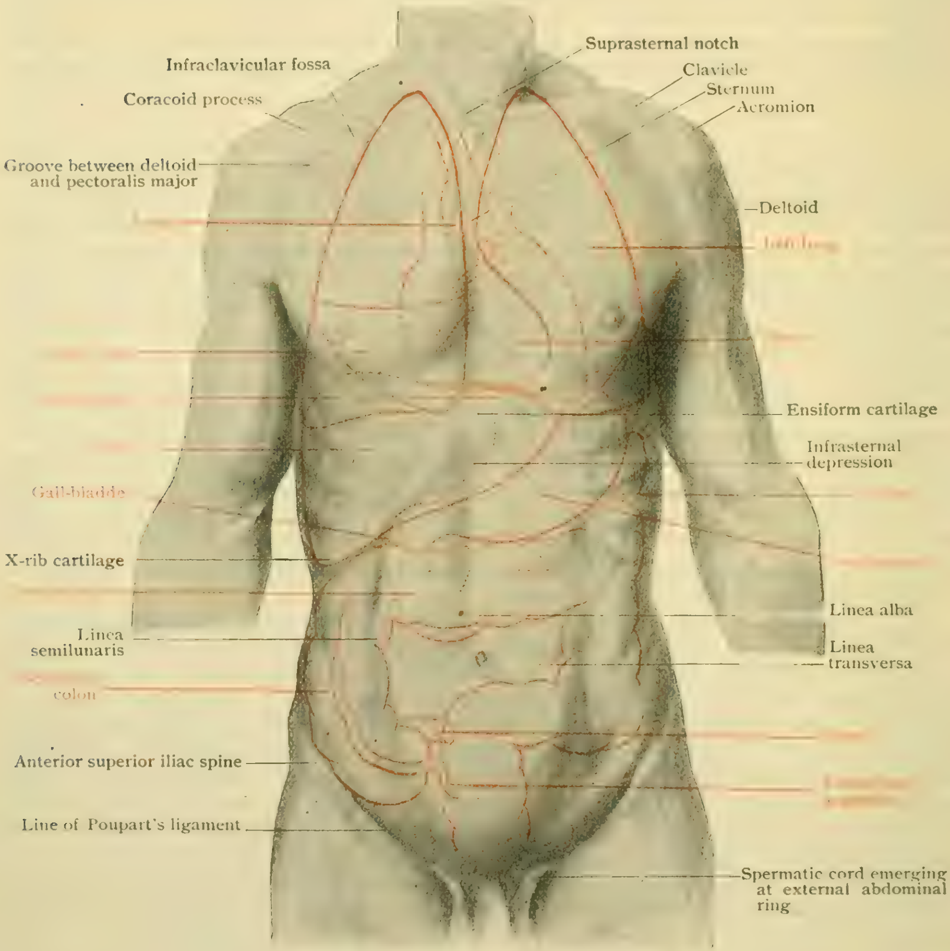
It has been so long the custom to divide the abdomen into nine regions by drawing two vertical and two transverse lines on the anterior wall, that the names applied to these conventional regions must be retained for general and vague use, although the method is inadequate for accurate description.[1] Hardly two authorities agree as to the location of the lines, but for general purposes the following suffices. Draw a vertical line upward from the middle of Poupart's ligament on each side. Let the upper transverse line cross these at their points of contact with the lower borders of the costal cartilages ; let the lower line connect the anterior superior spines of the ilia. The three middle regions thus mapped out are named, from above downward, *epigastric*, *umbilical*, and *hypogastric;* the lateral ones, the right and left *hypochondriac*, *lumbar*, and *iliac*. The advantage of this method is that the vertical lines approximately represent the borders of the median divisions of the two lower zones, and the lower cross-line is near the level of the sacral promontory.

The abdominal cavity is lined by a serous membrane, the *peritoneum*, which, in addition to covering the walls of the space, forms a more or less extensive investment for the abdominal organs. The latter, however, all lie really without the cavity of the peritoneal sac, the serous membrane being pushed in by the viscera. When the latter remain attached to the body-wall, as the kidneys, the peritoneal reflection is limited ; if, on the contrary, the organ becomes otherwise free, as the small intestine, the serous covering forms practically a complete investment. The latter is, however, never absolutely complete, since there is always an uncovered area through which the blood-vessels, lymphatics, and nerves reach the organs. The detailed description of the complex relations of the peritoneum will be given later (page 1740) ; suffice it

[1] The information conveyed by this method is of the same nature as that given by saying that Boston is north of Washington and Chicago west of it.

now, in anticipation of the references to peritoneal relations which necessarily follow in the consideration of the organs, to point out that the *parietal* and *visceral* portions of the serous membrane are continuous, the former investing the abdominal walls, the latter the organs. The peritoneal folds passing from a viscus to the body-wall have received in many cases the name *ligaments*, although often such bands contribute little support. The intestinal canal was originally attached to the abdominal wall by a fold covering vessels and nerves named the *mesentery*, parts of which per-

FIG. 1365.



Anterior surface of body, drawn from photograph. General relations of thoracic and abdominal organs to body-wall are shown by colored outline.

sist as free folds, while others fuse with the abdominal walls. The term *mesentery* is vaguely applied to that portion going to the jejuno-ileum, while other parts are distinguished by the name of the part of the intestine to which they are attached, as *mesocolon*. The term *omentum* is applied to folds attached to the stomach, as the *gastro-hepatic omentum*. The peritoneal sac is entirely closed, except in the female at the upper end of the oviduct, where the mucous membrane of the tube and the serous lining are directly continuous. The opposed smooth walls of the peritoneal sac are

in contact and lubricated with a thin layer of serous fluid, secreted by the membrane, by which friction between the organs and movable surfaces is reduced to a minimum.

The serous membrane, consisting of the endothelium and the fibro-elastic tunica propria, is attached to the subjacent fasciæ of the abdominal wall and the organs by a layer of *subperitoneal tissue*, an areolar stratum forming a more or less intimate connection between the serous coat and the structures which it covers.

The relations and attachments of the peritoneum observed in the adult are in some places entirely different from those existing in early life; hence the history of the changes occurring during development is essential for understanding the complex relations found at later periods.

PLAN OF THE DIGESTIVE TRACT BELOW THE DIAPHRAGM.

The subdiaphragmatic digestive tube is divided into the *stomach*, the *small intestine*, and the *large intestine*. The small intestine is subdivided into the *duodenum* and the *jejuno-ileum*. The former of these is an imperfect ring or horseshoe-shaped portion from 25–30 cm. (10–12 in.) long, all of which, except the first inch or two, lies on the posterior abdominal wall behind the peritoneum in the adult; then comes something over 6 m. (usually about 21.5 ft.) of intestine thrown into folds by its attachment to the free edge of the mesentery. The upper two-fifths of this is called the *jejunum* and the rest the *ileum*; but, as the division is arbitrary, it is better to speak of this portion of the small intestine as the *jejuno-ileum*, sometimes alluding to the upper part as *jejunum* and to the lower as *ileum*. It ends at the right iliac fossa by joining the *large intestine*, a little over 1.5 m. (usually about 5.5 ft.) long, which is subdivided into the *cæcum*, a blind pouch, and the *colon*, which is *ascending* in the right flank, *transverse* across the middle of the abdomen, and *descending* on the left. This is followed at the crest of the ileum by the *sigmoid flexure*, a free fold attached to the left of the pelvis, usually reckoned as a part of the colon, which, after crossing the left sacro-iliac joint, descends in the hollow of the sacrum, to become the *rectum* at the third sacral vertebra. The termination of the gut, passing through the thickness of the floor of the pelvis, is the *anal canal*. Two large glands —the *liver* and the *pancreas*—pour their secretions into the second part of the duodenum, from which they originally sprouted.

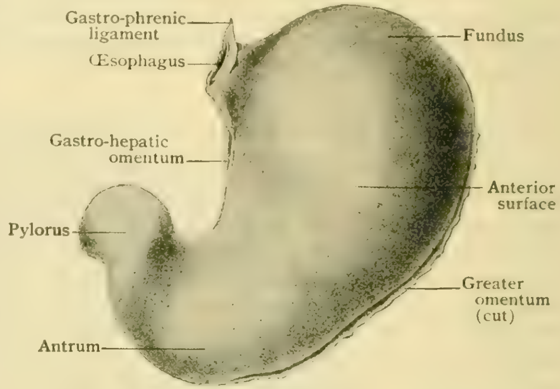
The liver, the stomach, and the spleen occupy nearly all the space in the dome-like upper zone of the abdomen; the right kidney, cæcum, and ascending colon on the right, the left kidney and the descending colon on the left, occupy the lower lateral recesses, leaving the middle space—shallow in the umbilical region and deep below it—for all the rest of the intestines, except such parts as can be squeezed into the preceding regions, and for the greater part of the pancreas.

THE STOMACH.

The stomach, the most dilated part of the digestive tube, follows the œsophagus, lying in the upper part of the abdomen below the diaphragm on the left, and passing downward and inward across the median line. In the early embryo it is a tubular dilatation, but it becomes flattened from side to side and the posterior border develops excessively, so that it rises above the upper opening and descends below the lower one. The stomach also swings on its long axis, so that its posterior border is carried to the left and the original left side to the front. The *lesser curvature* is that part of the right border of the stomach between the two orifices. It is straight or nearly so, and runs downward and forward to near its end, when it rises and passes to the right. The lesser omentum, originally the anterior mesentery, is attached to it. The *greater curvature* is more difficult to define. It is usually erroneously described as identical with the line of attachment of the greater omentum. It is more accurate to define it as the line from one orifice to the other which passes along the left side of the stomach and separates the anterior from the posterior aspect. The greater omentum—the modified posterior mesentery—is attached to the greater curvature all along except at the upper part, where it passes onto the posterior surface.

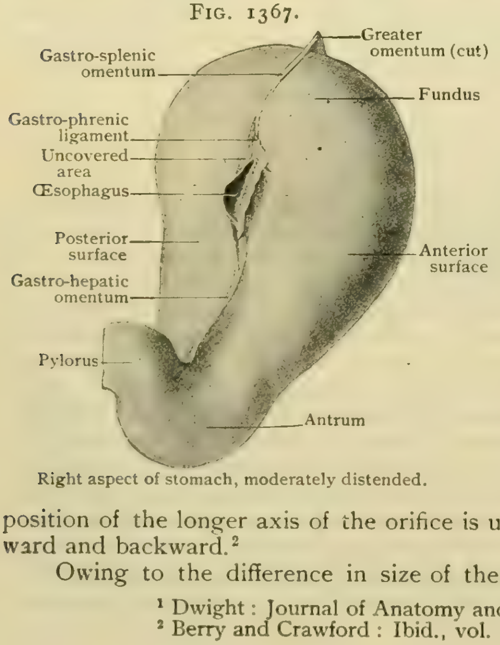
The **shape** of the stomach may be compared to that of a pear, somewhat flattened, with the large end up and the point bent to the right. The *fundus* is the highest part of the stomach which projects upward above the level of the end of the œsophagus. The greatest breadth of the stomach is at about the level of the œsophageal or cardiac orifice, and exceeds the antero-posterior diameter. The fundus generally contains air, if nothing else, and is somewhat distended, although thrown into uncertain contours by the partial contraction of its walls. Towards the lower or *pyloric end* the stomach gradually becomes more tubular, but the termination is often dilated into a cavity known as the *antrum pylori*. The constriction on its left may be very slight, so that the antrum is hardly to be seen, or it may be so deep as to be mistaken for the pylorus. The antrum may be double or even triple. Sometimes, on the other hand, the terminal part of the stomach is tubular and to be distinguished from the intestine only by its thick walls. Fig. 1368 shows such a case which seems to extend beyond the usual limits of the stomach. The superior or *cardiac orifice* faces upward and to the right, being much nearer the front than the back of the stomach. Its diameter is at least 2 cm. and may be much more. When the stomach is distended a well-defined groove appears between the fundus and the left of the œsophagus. Further details have been given with the gullet (page 1609). The position of the lower orifice or *pylorus* may not be recognizable on the outer surface, or it may be marked by a groove. Internally, it presents a distinct ring caused by the thickening of the layer of circular muscular fibres, improperly called the valve of the pylorus, which raises the mucous membrane. This can always be felt through the walls. It is only by touch that the position of the pylorus can be certainly recognized when the parts are unopened. The gastric cavity gradually narrows towards the pylorus on the stomach side, but from the duodenum there seems to be a perforated partition across the tube like an optical diaphragm. The opening, although nearly always elliptical, is sometimes almost circular. Some of the larger openings in a series of thirty casts[1] show a long diameter of from 17–18 mm. and a short one of from 13–15 mm. Some of the smaller openings measure 6 x 7 mm. and 8 x 8 mm. We have observed more extreme figures at both ends of the series than those quoted. It is difficult to say whether some of the smaller ones would admit of greater dilatation. Probably 13 x 15 mm. is not far from the average size. The position of the longer axis of the orifice is uncertain, although it usually runs downward and backward.[2]

Fig. 1366.



Anterior aspect of stomach, moderately distended.

Fig. 1367.



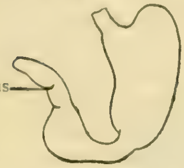
Right aspect of stomach, moderately distended.

Owing to the difference in size of the two ends of the organ, the *axis of the*

[1] Dwight: Journal of Anatomy and Physiology, vol. xxxi., 1897.
[2] Berry and Crawford: Ibid., vol. xxxvi., 1902.

stomach is necessarily oblique, although the lesser curvature is vertical until near its end. The axis slants downward and to the right as well as forward, the pyloric portion being disregarded. The stomach is sometimes comparatively tubular, the fundus being but little developed, although the cardiac opening is always on the right side. This is a continuation of the fœtal form, and is more often seen in women. There is often (possibly normally) a hint of a constriction about the middle.

FIG. 1368.



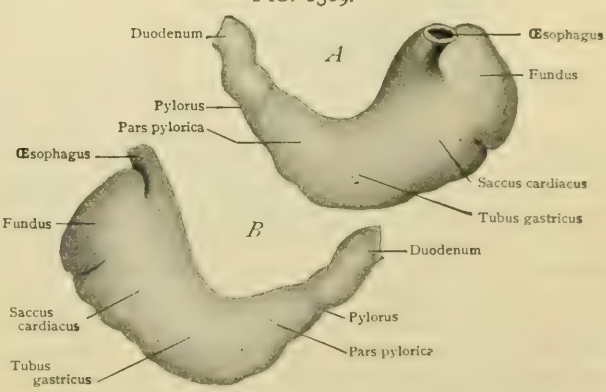
Outline of stomach with constricted and greatly elongated pylorus.

The foregoing conventional description is that of a distended stomach. The shape of the stomach during life, when not distended, is probably much more tubular, the greater part of the organ being often reduced to almost the diameter of the duodenum. Based on the divisions of the fœtal organ (Fig. 1369), Schwalbe recognizes three chief segments in the adult stomach : (1) *saccus cardiacus*, the upper part which remains saccular even during contraction ; (2) *tubus gastricus*, the lower part which, when contracted, resembles the intestine; and (3) *pars pylorica*, subdivided into the pyloric vestibule and canal. Local contractions of the muscular coat account for many irregular forms of the stomach.

Weight and Dimensions.—Not only is the normal development of the stomach very variable, but it is impossible to define the limits between the normal and the pathological ; naturally, therefore, statements differ widely and are of little value. According to Glendinning, the weight is 127 gm. (4½ oz.) for man and a little less for woman. The greatest length, directed nearly vertically, is some 25 cm. (10 in.), the greatest breadth from 10–12 cm. (4-5 in.), and its diameter from before backward from 7.5–10 cm. (3–4 in.). The average adult capacity is said to range from 600–2000 cc. (1.25–4.25 pints), with an average of 1200 cc. (2.50 pints).

Peritoneal Relations.—The greater omentum, the original posterior mesentery, passes to the back of the stomach just to the left of the œsophagus, where its layers diverge so as to leave a small triangular part behind it attached to the diaphragm without peritoneal covering. The lower of the diverging lines runs to the lesser omentum. The line of attachment then passes across the posterior surface of the fundus near the top, but posterior to the greater curvature. At the left of the stomach the line of insertion is at the greater curvature, and continues so till it reaches the pylorus. The fold passing to the diaphragm at the beginning is the *gastro-phrenic ligament.* This is joined by the *gastro-pancreatic fold* on the posterior abdominal wall which conveys the coronary artery to the right of the cardiac opening. This last fold is important in relation to the typography of the peritoneum, but not to the stomach. The lesser omentum is attached along the whole of the lesser curvature, except that its posterior layer may leave it below the cardia to join on the back of the stomach the layer of the greater omentum which forms the inferior border of the non-serous triangle. With the exception of this triangle, and of the trifling interval between the lines of attachment of the omenta, the whole organ is invested by peritoneum.

FIG. 1369.

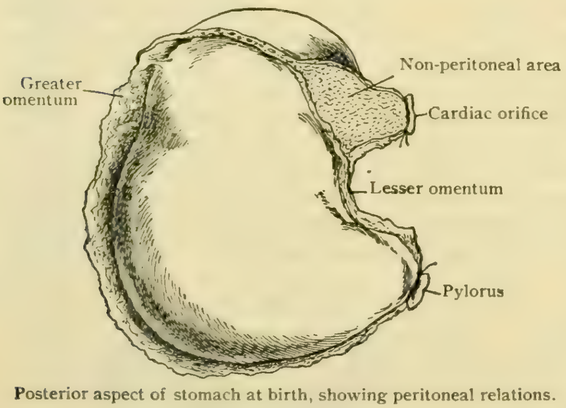


Anterior (*A*) and posterior (*B*) aspects of stomach of human fœtus of 205 mm. (*Schwalbe.*)

Position and Relations.—The *cardiac opening* is opposite the tenth thoracic vertebra and not far from the level of, but from 8–10 cm. (3–4 in.) behind, the sixth left costal cartilage, about 12 mm. (½ in.) to the left of the median line. The lesser curvature descends vertically in an antero-posterior plane, parallel to the left border of the ensiform, but slanting strongly forward, until it suddenly turns to the

right, rises, and ends opposite the space between the ensiform and the end of the eighth or ninth right costal cartilage, on a level with the first lumbar vertebra or the disk below it, about 1.2 cm. (½ in.) from the median line. The *pyloric orifice* is affected to such an extent by changes incident to variations in distention that it is manifestly impossible definitely to fix the position of the lower end of the stomach. The pylorus is usually separated from the anterior abdominal wall by the overlapping liver, when the stomach is empty lying near the mid-line. According to Addison, a point 12 mm. (½ inch) to the right of the median plane midway between the top of the sternum and the pubic crest will ordinarily correspond to the position of the pylorus. The *fundus* is at the top of the left side of the abdomen under the diaphragm, reaching the level of the sternal end of the fifth costal cartilage. The anterior surface, looking upward as well as forward, is covered by the left and quadrate lobes of the liver. A varying part of it touches the diaphragm in front of the former. The extent of this must depend on the size of both organs. The liver may separate it entirely from that part of the diaphragm below the pericardium, or the stomach may be against the diaphragm in the anterior part of this region. A small triangular part of the stomach, normally in contact with the front wall of the abdomen, bounded below by the greater curvature, is seen, on opening the abdomen, between the liver and the line of the left costal cartilages. This appearance gave rise to the old error that the stomach is placed transversely. According to Tillaux, the stomach in its most contracted state always descends to a line between the ends of the ninth costal cartilages. The posterior surface, forming a part of the anterior wall of the lesser peritoneal cavity, rests against the transverse mesocolon, which lies on the organs at the back of that space, so as to make a part of the concavity for it which Birmingham[1] has well called the *stomach-bed* (Fig. 1371). This hollow is made by the diaphragm on the left of the aorta, by the left suprarenal capsule, the gastric surface of the spleen, the antero-superior surface of the pancreas, and usually by the upper part of the left kidney, although exceptionally this may be shut off from the stomach by the spleen and pancreas. The left crus of the diaphragm makes a deep indentation in the stomach to the left of the cardia. The cœliac axis and the semilunar ganglia are rather to the right of the lesser curvature. The transverse mesocolon continues the lower part of the stomach-bed forward to the transverse colon, which lies below the stomach, following its curve when the stomach is distended. The splenic flexure of the colon is close against it. When free from solid contents, the stomach is usually found in dissecting-room subjects hanging more or less vertically in longitudinal folds containing more or less air and fluid ; but during life, as already stated, it is in a contracted and puckered condition, the long axis running strongly forward as well as downward. With distention the stomach enlarges at first upward, backward, and to the left, then forward against the abdominal walls. The upper part enlarges chiefly backward, the lower forward. This does not imply a forward swing of the greater curvature such as has been described. The pyloric end is moved to the right, it may be as far as the gall-bladder. The antrum may thus, according to Birmingham, be carried to the right of the pylorus. The latter rarely moves more than 5 cm. to the right of the median line. Except in its last part, the lesser curvature continues essentially vertical, as seen from before. The transverse colon is driven downward unless it be so much distended as to offer effectual resistance.

FIG. 1370.



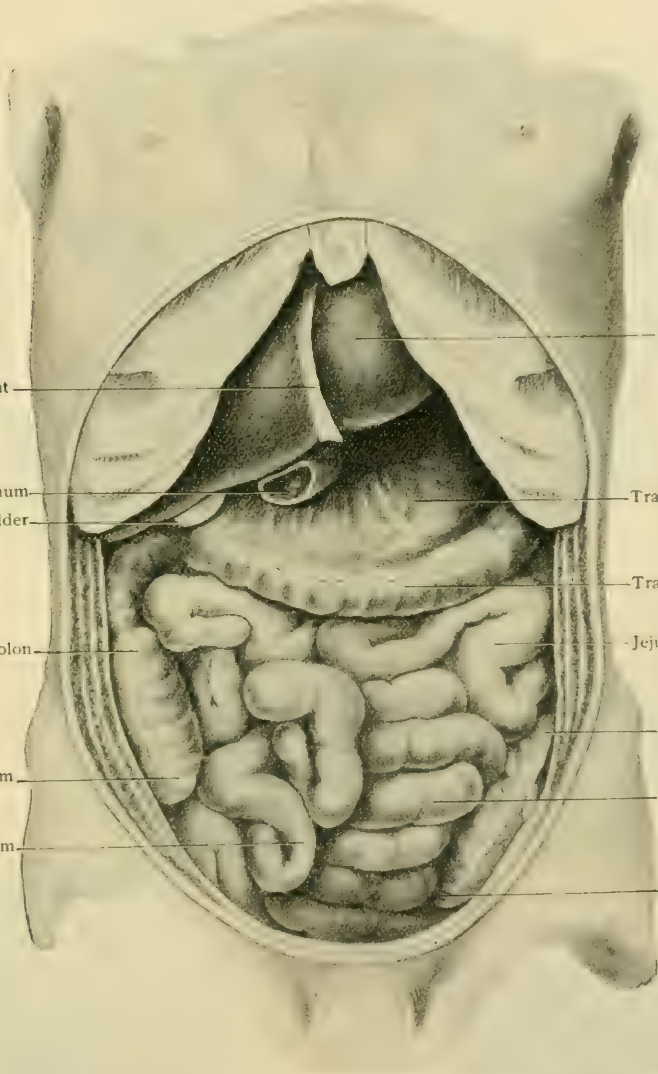
Posterior aspect of stomach at birth, showing peritoneal relations.

[1] Journal of Anatomy and Physiology, vols. xxxi., xxxv., 1897, 1901.

Structure.—The walls of the stomach, thickest and most resistant near the pylorus, consist of four coats,—the mucous, the submucous or areolar, the muscular, and the serous.

The **mucous coat** or *mucosa* is soft and velvety, easily movable on the lax subjacent areolar tissue, thickest near the pylorus, and presents many folds or *rugæ*, which during distention are more or less completely effaced. The folds are in the

FIG. 1371.



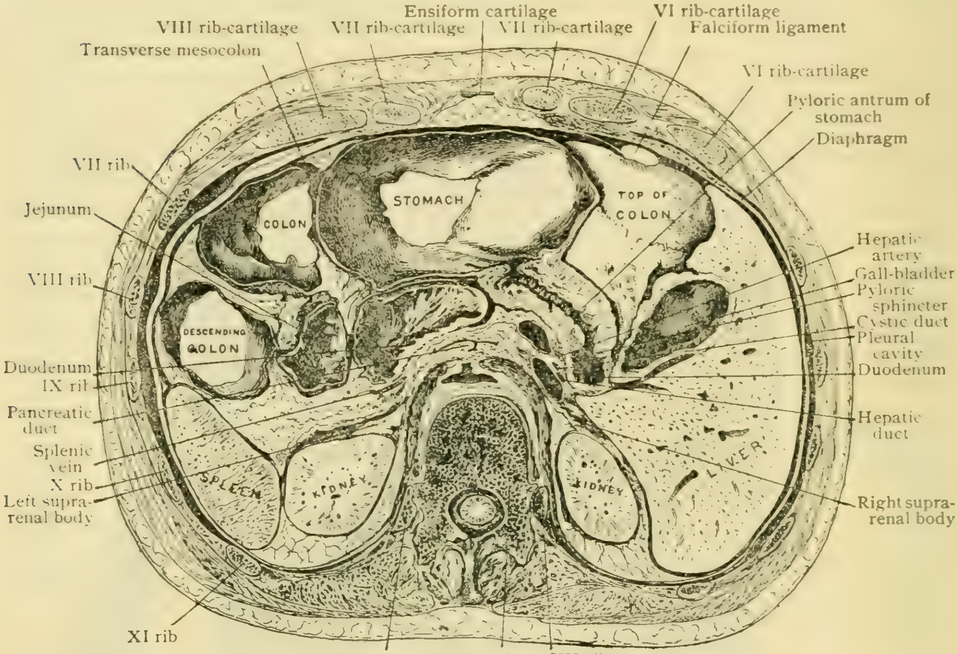
Abdominal organs of formalin subject; stomach has been removed to show that part of its "bed" formed by transverse mesocolon and colon.

main longitudinal, especially at the pyloric end, but many smaller ones run in all directions.

The *epithelium* covering the free surface of the mucous membrane consists of a simple layer of tall columnar elements, from .020–.030 mm. in height, many of which are goblet-cells engaged in producing the mucus lubricating the gastric surface. At the passage of the œsophagus into the stomach, some 2–3 cm. below the diaphragm, the opaque stratified squamous epithelium of the gullet abruptly changes into the

transparent columnar cells clothing the stomach. The line of transition is zigzag and well defined, the œsophageal surface being paler than the highly vascular red gastric mucosa. At the pylorus the mucous membrane is raised into a ring, chiefly

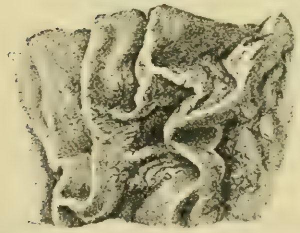
FIG. 1372.



Frozen section across body at level of twelfth thoracic vertebra.

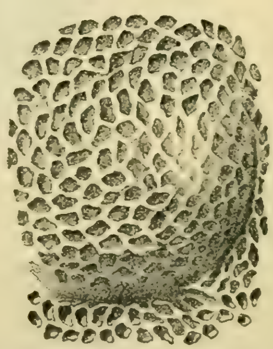
in consequence of the local thickening of the circular fibres of the muscular coat, but also in part on account of the increased thickness of the mucosa itself, which in this part of the stomach may measure over 2 mm. At the cardia it is thinnest,—.5 mm. or less,—while in the intermediate region it is about 1 mm. The increased thickness at the pyloric end is due to the considerable depth of the depressions, or

FIG. 1373.



Surface view of mucous membrane from pyloric end of stomach. Natural size.

FIG. 1374.



Surface view of gastric mucous membrane, showing reticular appearance due to orifices of groups of gastric glands. × 30.

gastric crypts, into which open the gastric glands. Beyond the summit of the pyloric ring the mucous membrane assumes the characteristics of the intestine. In addition to the larger rugæ, the gastric surface exhibits a mammillated condition

consisting of small polygonal areas pitted by the crypts which receive the orifices of the glands.

The **gastric glands** constitute two principal groups, the *fundus* and the *pyloric glands;* the former occupy the major part of the stomach, including the fundus, the anterior and posterior walls, and the curvatures; the latter occur in the pyloric fifth of the organ. An additional fundus variety—the *cardiac glands*—is represented by a narrow zonular group in the immediate vicinity of the œsophageal opening.

The fundus or peptic glands—the gastric glands proper—consist of numerous closely set tubules, usually somewhat wavy and from .4–2 mm. long, which extend the entire thickness of the mucosa and abut against the muscularis mucosæ. Each gastric crypt, corresponding to the *excretory duct*, usually receives a group of several of the smaller tubules, which include the *body* and *fundus* of the gland, the constricted commencement of the tubule constituting the *neck*. At the latter position

FIG. 1375.

Transverse section of stomach (left end), showing general arrangement of coats. × 20.

the columnar epithelium prolonged into the crypts from the free surface becomes lower and modified into the secreting elements.

The cells lining the gastric tubules are of two kinds, the chief and the parietal.

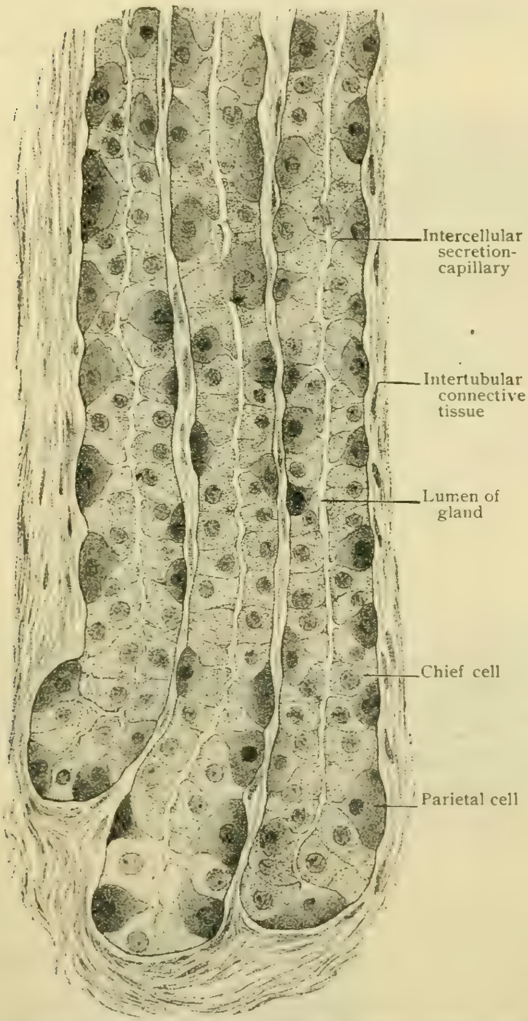
The *chief*, *central* or *adelomorphous cells* correspond to ordinary glandular epithelium, being low columnar or pyramidal, and surrounding a circular lumen from .002 to .007 mm. in diameter. During certain stages of digestion they contain numerous granules, which are probably concerned in producing pepsin.

The *parietal cells*, known also as acid, oxyntic, or delomorphous, although relatively few, are conspicuous elements which occupy the periphery of the gland-tubes. Their position is indicated by protrusions of the profile of the gastric tubules caused by the cells lying immediately beneath the basement membrane. The parietal cells, although arranged with little regularity, are most numerous in the vicinity of the neck, where they may equal or even outnumber the central cells; in the body of the

gland they decrease in number towards the fundus, in which locality they may be almost absent. Their protoplasm is finely granular and lighter than that of the chief cells. The parietal cells, although apparently excluded by the central ones, are connected with the gland-lumen by means of lateral intercellular secretion-capillaries; the latter extend from the axial space to the peripherally situated elements, over which they form characteristic basket-like net-works.

The **pyloric glands,** branched tubular in type, differ from the fundus glands in the excessive width and depth of their excretory ducts, into which a group of relatively short but very tortuous gland-tubules opens, and in the simple character of their lining. The latter consists of a single layer of low columnar or pyramidal elements, which correspond to and resemble the chief cells of the fundus glands. Their secretion often reacts as mucus (Bensley). Owing to the tortuous course of the pyloric tubules, the deeper parts of the glands are cut in all planes, portions of the same tubule often appearing as isolated transverse, oblique, or longitudinal sections. The transitional or intermediate zone connecting the pyloric and adjoining portions of the stomach contains both forms of glands, those of the fundus variety with parietal cells being intermingled with the pyloric type. Towards the intestine the change of the pyloric glands into those of the duodenum is gradual, the gastric tubules sinking deeper until, as the glands of Brunner, they occupy the submucous coat of the intestine.

FIG. 1376.



Deeper portion of gastric glands from fundus, showing two varieties of lining cells and secretion-capillaries connecting parietal cells with lumen. × 423.

The **cardiac glands** form a narrow annular group, some 5 mm. broad, surrounding the orifice of the gullet, into which they are continued for a short distance (page 1612). These glands, which in some animals constitute a much wider zone (in the hog almost a third of the entire stomach), are to be regarded as modified fundus glands (Oppel), since they possess similar epithelium, including usually a few parietal cells. Their excretory ducts or crypts, lined with the gastric epithelium, often exhibit ampulla-like dilatations. Among the typical tubules are a few shorter ones which recall the glands of Lieberkühn of the intestine, since they contain goblet-cells and exhibit a cuticular border (J. Schaffer).

The *stroma* or tunica propria of the gastric mucous membrane consists of a loose fibro-elastic connective tissue containing numerous cells and resembling lymphoid tissue, which fills the interstices between the glands and, in conjunction with the extensions of the muscularis mucosæ, forms envelopes and partitions for the groups of tubules constituting the deeper parts of the gastric glands. In

the vicinity of the pylorus, and sometimes also at the cardia, a number of small lymphatic nodes—the so-called *lenticular glands*—normally occupy the deeper parts of the mucosa; occasionally they are of sufficient size to almost reach the free surface.

The *muscularis mucosæ*, as in other parts of the intestinal tube, consists of a well-marked collection of involuntary muscle, deeply situated next the submucous coat. Two layers are usually distinguishable, an inner circular and an outer longitudinal.

FIG. 1377.

Transverse section of stomach, pyloric end; ruga is cut across, showing mucosa supported by core of submucous tissue. × 20.

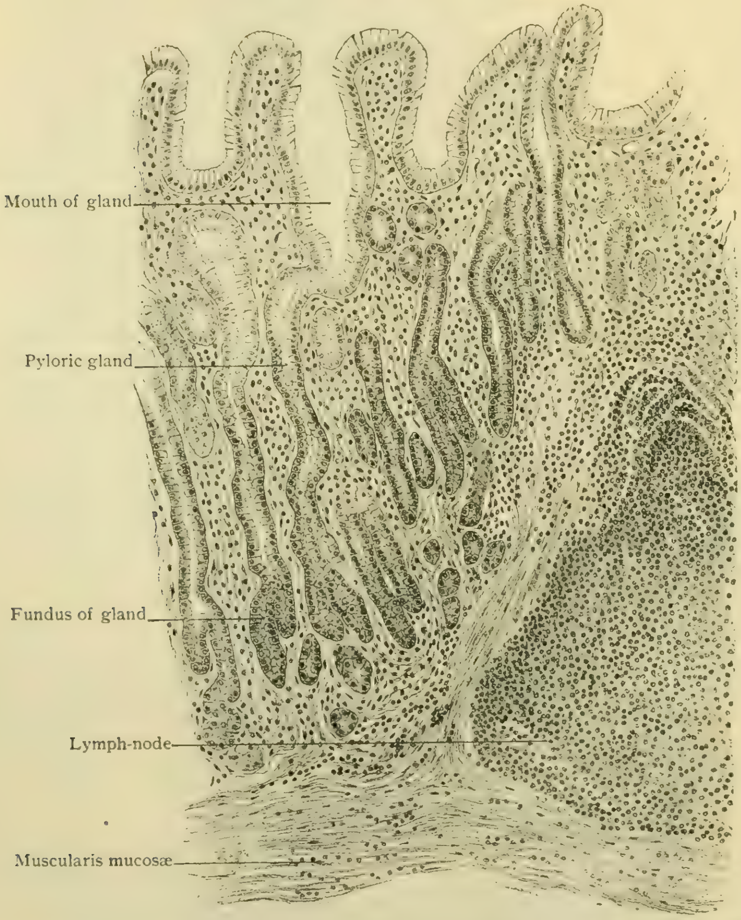
tudinal. Towards the mucosa numerous bundles of muscle-cells extend between the glands and in places penetrate almost as far as the epithelium.

The **submucous coat** consists of lax connective tissue, allowing the mucous membrane to move freely on the muscular layer. It contains blood-vessels of considerable size, a mesh-work of lymphatics, and the nerve-plexus of Meissner.

The **muscular coat** comprises three layers,—an outer longitudinal, a middle circular, and an imperfect inner oblique,—of which the middle one is the most

important. This layer is composed of *circular fibres*, which are thickest and most simply arranged near the pylorus. Owing to the enlargement of the upper end of the stomach, and the fact that the cardiac opening is not at the end but at the side, the arrangement becomes complicated. The fibres surround the cardia, but become oblique at a short distance from it. At the top of the fundus they are arranged in a whorl mingling with those of the internal layer. Still lower, although in the main circular, their course is uncertain. Towards the pylorus they thicken considerably, being particularly well developed in stomachs of which the pyloric part is tubular. At the opening they are collected into a ring—the *pyloric sphincter*—capable of closing the orifice. The *longitudinal layer* is outside of the circular one and continuous

FIG. 1378.



Section of pyloric end of stomach, showing glands and part of lymph-node. × 100.

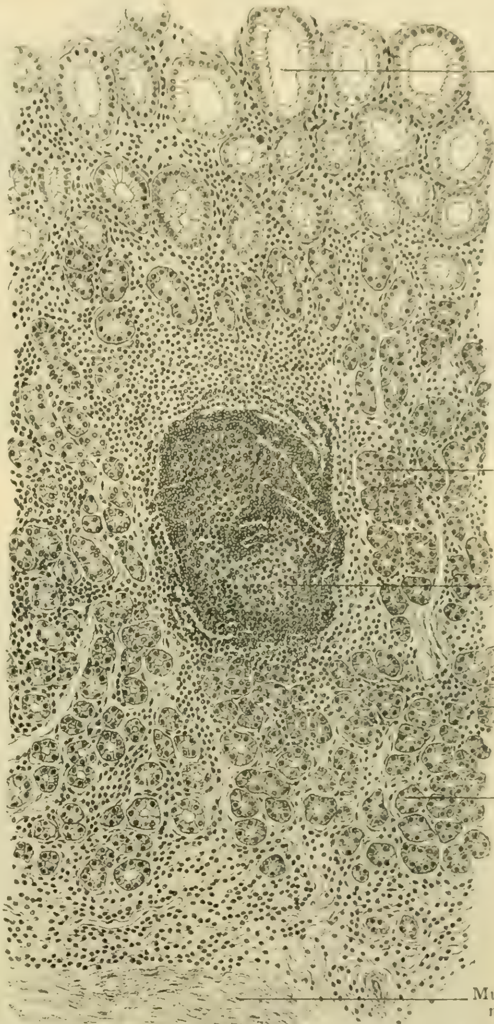
with the longitudinal fibres of the œsophagus. Along the lesser curvature, and to a less extent along the greater, these fibres are collected into bands ; over the front and the back of the stomach they are oblique. At the antrum pylori, although the layer is continuous all around, it presents an anterior and a posterior band,—the *pyloric ligaments*,—that pass over folds of all the layers internal to them, thus forming the duplicature at the beginning of the antrum. At the pylorus itself the longitudinal layer, which has become thicker, sends a series of fibres through the circular fibres, subdividing them into many groups, (Fig. 1391). The innermost muscular layer consists of *oblique fibres* spreading out from the cardia over the front and back of the stomach. They are continuations of the circular fibres of

the gullet and diverge to either side, showing a well-marked border near the lesser curvature. Their posterior expansion is the stronger. The diverging fibres are lost near the pylorus, while in the vicinity of the fundus they mingle with the circular ones that form the whorl. The latter, according to Birmingham, is formed by this layer alone.

The **serous coat** corresponds in structure with other portions of the peritoneum, consisting of the endothelium of the free surface, beneath which lies the fibro-elastic stroma attached to the muscular tunic.

Blood-Vessels. – The *arteries* of the stomach, derived from the cœliac axis, are arranged in two arches along the lines of attachment of the omenta; hence that which is attached to the greater curvature below passes behind it on the fundus. The arch along the lesser curvature is formed by the gastric artery, which sends an œsophageal branch upward to meet the lowest of the œsophageal arteries, and joins the pyloric branch of the hepatic artery below. The arteries of the greater omentum are the right and left gastro-epiploic, reinforced behind the fundus by the vasa brevia of the splenic artery. The gastro-epiploica dextra passes down on the right of the first part of the duodenum close to the pylorus; branches arising on the front at that region may nearly or quite make an arterial ring around the organ. The gastric artery supplies the longer branches to the walls, there being a richer arterial distribution on the back than on the front and at the cardiac than at the pyloric end. The general plan is as follows: on the anterior surface several arteries, of which some four are large ones, run from the lesser curvature across the stomach, sending out successive lateral branches to inosculate with those from their fellows; finally, the main vessel breaks up into branches that meet those from the greater curvature. On the posterior surface the chief trunks divide with less regularity. At first the arteries are just beneath the peritoneum, between the folds of which they gain the stomach; presently they enter and pierce the muscular coat, the outer parts of which are supplied during their passage. On reaching the submucous coat the arteries, now reduced, but still of considerable size, divide into smaller branches, some of which pass to the muscular tunic, while the majority enter the mucous coat. The latter soon break up into capillaries which surround the gland-

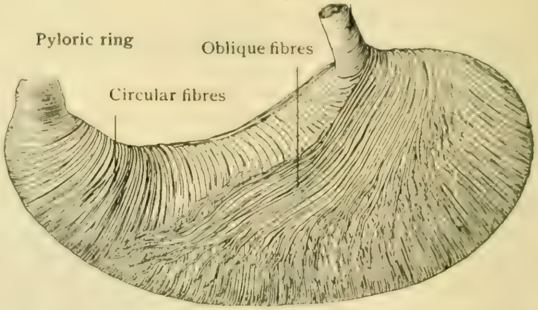
FIG. 1379.



Oblique section of mucous membrane from pyloric end of stomach, showing glands cut at various levels. × 100.

tubules with a close mesh-work. Somewhat larger capillaries constitute a superficial plexus beneath the epithelium encircling the orifices of the gastric crypts. The *veins*, relatively wide, begin in the subepithelial capillary net-work and traverse the gland-layer, between which and the muscularis mucosæ they form a plexus; from the latter radicles pass into the submucous coat, in which the venous trunks run parallel with the arteries, but lie nearer the mucosa (Mall). The emerging tributaries are often provided with valves at their junction with the larger gastric veins.

FIG. 1380.

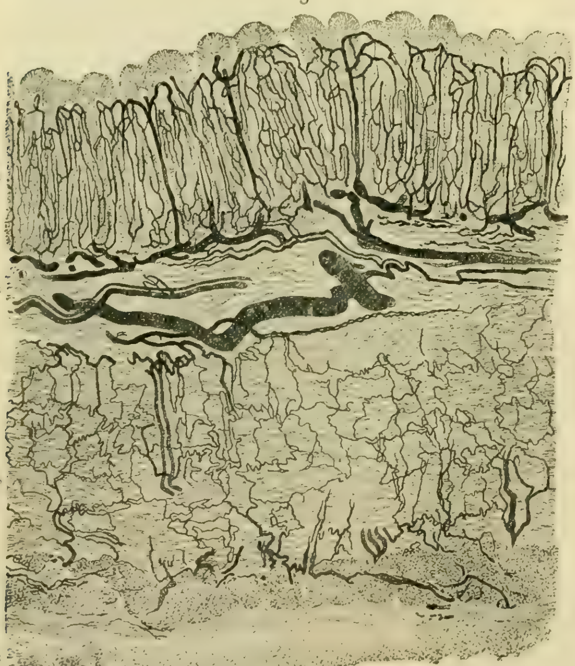


Stomach turned inside out, showing dissection of oblique and circular muscular coats.

The **lymphatics** originate within the mucous membrane, beneath the epithelium, as wide, irregular capillary channels which freely communicate with one another and pass between the glands as far as the muscularis mucosæ; at this level they form a plexus from which vessels descend into the areolar coat to join the wide-meshed submucous plexus. Larger lymphatics pierce the muscular tunic and unite to form the chief channels which escape from the walls of the stomach along both curvatures to empty into the lymph-nodes which occur in these situations.

The **nerves** supplying the stomach are from the pneumogastric and the sympathetic, and contain both medullated and nonmedullated fibres, the latter predominating. On reaching the organ, the stems pierce the external longitudinal muscular layer, between which and the circular layer they form the *plexus of Auerbach*. The points of juncture in this net-work are marked by microscopic sympathetic ganglia, from which non-medullated fibres supply the involuntary muscle. Leaving the intramuscular plexus, twigs pass obliquely through the circular muscular tunic, and on gaining the submucous coat form a second net-work, the *plexus of Meissner*. Numerous non-medullated fibres leave the latter to enter the mucous coat, in which some end in delicate plexuses supplying the gastric glands (Kytmanow), as well as in special endings in the muscularis mucosæ (Berkley). Large medullated fibres, the dendrites of sensory neurones, are also present within the mucosa, where they form a subepithelial plexus after losing their medullary substance. The ultimate termi-

FIG. 1381.

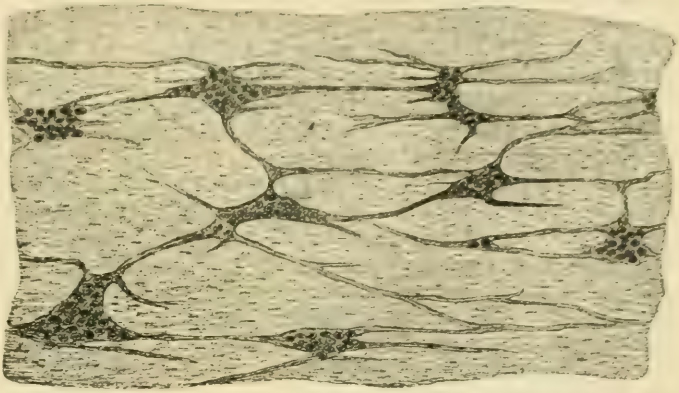


Transverse section of injected stomach. × 50.

nations of the nerve-fibres within the mucosa, especially their relations with the gland-cells, are still uncertain.

Growth.—At birth the capacity of the stomach is 25 cc. The organ, although sometimes rather tubular, does not differ very much in shape from that of the adult. The œsophagus enters it less obliquely than later, so that regurgitation occurs more readily. The sphincter of the pylorus is already developed. We do not remember ever to have seen at birth a well-marked antrum pylori. An important peculiarity of the growth of the stomach is the unequal development of the two sides at the fundus. At an early period the top of the original left side, which becomes the anterior one, grows upward, so that the line of attachment of the greater omentum is along the posterior surface. This unequal growth is quite analogous to that of the cæcum. According to Keith and Jones, this asymmetry is most marked in the third and fourth months of fœtal life. We have examined no younger fœtuses than these, and cannot state how early the process begins.[1] From the end of the first week after birth the growth of the stomach is very rapid during the first three months. It is slow in the fourth month, and in the two months following it is almost quiescent.[2] We have seen it at a few weeks relatively broader than in the adult. While it is probable that individual variations show themselves early, the shape and size of the stomach depend, beyond question, to a great extent on the nature and quantity of the food. With advancing years the stomach often becomes dilated, and, apart from dilatation, is likely to descend lower in the abdomen. The female stomach, except for its greater tendency to subdivision, differs less than the male from the fœtal form.

FIG. 1382.



Surface view of fragment of muscular coat of stomach, showing groups of ganglion-cells and nerve-fibres of plexus of Auerbach. × 70.

Variations.—Apart from those of size and shape, already alluded to, the important ones are those of subdivision. There may be a constriction at the middle dividing the organ into two chambers connected by a narrow passage: the "hour-glass stomach." There may also be a reduplication of the antrum, or, indeed, there may be three, or, on the other hand, the place of the antrum may be taken by a tube with thick walls. It is probable that these changes are sometimes caused by a local contraction becoming fixed.

PRACTICAL CONSIDERATIONS: THE STOMACH.

Congenital malformations are rare. Perhaps the most common is a constriction dividing it into two unequal compartments,—"hour-glass constriction,"—a condition somewhat similar to that found normally in the kangaroo.

The *position* of the stomach varies with its degree of distention. When it is empty the pyloric end descends and the long axis of the stomach is oblique from left to right, approximating the vertical (*i.e.*, the fœtal) position or that which preceded functional use. This falling of the pyloric end is due to gravity, the nearest firmly fixed point of the alimentary canal below being the lower portion of the duo-

[1] Priority of publication of this peculiarity of development belongs to Mr. Arthur Keith and to Mr. F. Wood Jones: Proceedings of the Anatomical Society of Great Britain and Ireland. Journal of Anatomy and Physiology, vol. xxxvi., 1902.
[2] Rotch's Pediatrics.

denum (the fixation being due to the relation of the superior mesenteric artery and to the root of the mesocolon in front), while above the cardiac end is suspended from the œsophagus and held in place by the gastro-phrenic and gastro-splenic ligaments. The transverse colon may then lie in front of the stomach and may, if distended, be taken for it. The empty stomach lies upon the posterior abdominal wall. If the emptiness is habitual, the pylorus will resemble the first portion of the duodenum and regurgitation of duodenal contents is exceptionally easy. The "gnawing pains" of hunger or starvation (distinct from the sensation of hunger itself) are at least partly due to the traction on the nerve-plexuses and filaments resulting from this altered position, and can, therefore, in many cases be relieved temporarily and partially by tightening the clothing about the waist and abdomen, giving support to the viscera.

When the stomach is distended the enlargement, which occurs at first upward and backward and towards the left side, raises the arch of the diaphragm in that region and with it the heart and pericardium. The gastric plexuses derived from the two pneumogastrics and the associated sympathetic fibres, together with the coronary plexus from the sympathetic, are all in close relation with the lesser curvature, especially its cardiac end. It is not, therefore, difficult to understand how this change in the position of the stomach aids in producing the flushed face, embarrassed respiration, and irregular heart action often seen in various forms of dyspepsia or after overeating. If distention continues, the right lobe of the liver is also pushed upward, the pylorus moves to the right, and the transverse colon downward ; the stomach comes in close contact with the anterior wall of the abdomen, the "scrobiculus cordis" (page 171) is obliterated, and a tympanitic note replaces the normal resonance.

Conversely, cardiac disease may cause vascular congestion of the stomach, catarrh, dyspepsia, or even hæmatemesis. The "black vomit" of moribund persons is due to a similarly produced distention and rupture of the stomach capillaries.

The position of the stomach varies with the respiratory movements. In forced inspiration the cardiac opening descends about one inch with the crura of the diaphragm ; the pylorus reaches about the level of the umbilicus.

Eructation of stomach contents in its typical form is accomplished by contraction of the muscular walls of the stomach ; *vomiting* by compression of the stomach against the under surfaces of the liver and diaphragm through contraction of the abdominal muscles. This is associated with contraction of the circular pyloric fibres and relaxation of the oblique fibres at the cardia, and is probably aided by contraction of the stomach walls themselves.

It is obvious that a full stomach is more easily and directly compressed in this way, and therefore the ingestion of large quantities of fluids favors emesis.

Vomiting is a clinical symptom often of the greatest significance, and should be studied in relation to the pneumogastric and sympathetic distribution to the stomach, lungs, and abdominal viscera ; and its various causes—central, reflex, and direct—should be worked out systematically.

Injuries of the Stomach.—The changes in position and the degree of distention are of the utmost importance in trauma expended upon the stomach, which, if quite empty, almost certainly escapes contusion and rupture. It is, at any rate, much less frequently ruptured than the intestines on account of its thicker walls and of the protection afforded it by the overhanging ribs and the interposed liver. The "stomach-bed" (page 1620) supplies an elastic and movable base of support, which also favors its escape from injury.

In penetrating or gunshot wounds its condition as to emptiness or the reverse is even more important. When either wall is opened by rupture or wound, eversion of the mucous membrane, which is favored by its thickness and by the laxity of the submucous connective tissue, may temporarily plug the opening, and through the formation of adhesions permit of spontaneous cure. The different directions of the muscular fibres in the three layers of that coat ordinarily prevent wide separation of the margins of the wound, and thus also favor its closure by natural processes. In escape of stomach contents through ulceration, wound, or rupture, if the posterior wall is involved, the lesser omental cavity is infected, and a localized—sub-

phrenic—abscess may follow; if the anterior wall is opened, infection of the general peritoneal cavity and septic peritonitis are more likely to result. On account of the course of the blood-vessels (page 1627), wounds parallel with the axes of the curvatures are attended by free bleeding, especially if near those borders of the stomach. Wounds running more or less at right angles to the curvatures and removed from them are much less likely to open large vessels. The vessels just beneath the surface of the mucous membrane are numerous but smaller. Bleeding from them may be controlled by separate suture of the mucosa, which is facilitated by its thickness and by the looseness of the submucous cellular tissue.

Ulcers of the stomach are found most often on the posterior wall at the pyloric end and along the lesser curvature. It has been suggested that they originate in a bacterial necrosis of the epithelium, which is favored by the absence of the fundus or peptic glands (page 1623) at this region, and is followed by "digestion" of the subjacent tissues. Allen thinks that the immense preponderance of pyloric ulcers is an illustration of the "law of localization of diseased action,"—viz., that parts enjoying the most rest are least liable to involvement by structural disease. When they cause hemorrhage, it is apt to be from the branches of the coronary artery. Perforation occurs with much greater frequency in ulcers situated on the anterior wall, which is the one with the greatest range of motion in varying stages of digestion and degrees of distention, and also during the movements of respiration. Perforation from such ulcers with spontaneous cure may result in adhesions between the stomach and pancreas, colon, duodenum, or gall-bladder, and may be followed by fistulæ communicating with those viscera. They may perforate the diaphragm and cause empyema. They have opened into the pericardium and into a ventricle of the heart. An ulcer may be so surrounded by adhesions that, even when on the anterior wall, perforation does not cause a general peritonitis, but a localized abscess. If this is, for example, in the splenic region, it will be observed that there is immobility of the upper left quadrant of the abdomen with restriction of the respiratory movements of the left thorax, both occasioned by the connection between the splanchnic and the intercostal nerves through the sympathetic ganglia. The localization of such collections of pus after perforation of the anterior wall near the cardia is favored by the "costo-colic" fold of peritoneum extending from the diaphragm opposite the tenth and eleventh ribs to the splenic flexure of the colon and forming part of the left portion of the "stomach-bed." This fold, especially with the patient supine, forms a "natural well," containing the spleen and a part of the stomach, into which any fluid exudate or stomach contents may gravitate (Box).

Cancer of the stomach occupies by preference the pyloric region. When the growth becomes palpable, but before it is tied down by adhesions to neighboring organs, it often illustrates the mobility of the pyloric end of the stomach (*vide supra*), as it can be pushed even across the mid-line of the body into the splenic region.

Carcinoma, according to its situation, may extend in the course of the lymphatic vessels running along the lesser curvature in the gastro-hepatic omentum and emptying into the lymph-nodes near the cœliac axis and hepatic blood-vessels, or along the greater curvature and the cardia to the retro-œsophageal glands. The retro-pyloric lymph-nodes may be invaded in cancer of the pylorus. Its early recognition as a tumor obviously depends upon its anatomical site. If it occupies the fundus, the cardia, the lesser curvature, or the upper and outlying portions of the anterior wall, the ribs and the liver intervene and prevent palpation of the growth; and if on the posterior wall, the depth at which the tumor lies renders its palpation difficult and unsatisfactory.

Dilatation of the stomach (*gastrectasis*) may be due to simple hypertrophy of the pyloric muscle, may follow stricture of the pylorus or duodenum from cicatrization of an ulcer, or may result from pyloric occlusion, as from carcinomatous growth invading the pylorus itself, or from pressure of an extrinsic tumor, or a displaced liver or right kidney. The distention is often extreme, and in some instances the outline of the distended stomach can plainly be seen, the lesser curvature a couple of inches below the ensiform cartilage and the greater curvature passing obliquely,

from the tip of the tenth rib on the left side, towards the pubes, and then curving upward to the right costal margin (Osler). The dilatation may be of any degree, the lower border of the stomach sometimes reaching to the level of the pubes.

Displacement of the stomach (*gastroptosis*) is attended by great stretching of the gastro-hepatic, gastro-splenic, and gastro-phrenic folds. It is sometimes a dilatation with the stomach vertical instead of oblique rather than a true descent of the whole organ.

Three forms are described: (1) a slight descent of the pylorus, and with it of the lesser curvature, so that the latter comes from beneath the liver; (2) "vertical stomach," already alluded to; (3) a descent of the lesser curvature, the pylorus remaining fixed, making a U-shaped stomach (Riegel). The last is very rare. All forms are favored by the use of corsets or clothing constricting the lower thorax, especially in women with flaccid abdominal walls. The displacement may be congenital, or may be due to primary elongation or relaxation of the peritoneal folds which act as ligaments, or to malposition or displacement of other abdominal viscera.

Hernia of the stomach is usually diaphragmatic and often congenital. The viscus may enter the thorax through a stab wound or rupture, or through weakened or enlarged spaces at (*a*) the central tendon, (*b*) the posterior inferior muscular area, (*c*) the interval between the sternal and costal fibres, (*d*) the œsophageal foramen, (*e*) the fissure between the lumbar and costal portions, or (*f*) the point of passage of the sympathetic trunk (Sultan). These possible locations have been mentioned in the order of frequency.

The hernia may carry the peritoneum with it (*true* hernia), as in cases of partial rupture or non-penetrating wound of the diaphragm, or may avoid or pass through the peritoneum (*false* hernia). The latter are more common. All forms are found most frequently on the left side in consequence of the presence of the liver on the right side.

Operations on the Stomach.—The stomach is most accessible for operation through a triangular space, apex upward, bounded on the left by the eighth and ninth costal cartilages, on the right by the free edge of the liver, and below by a horizontal line joining the tips of the tenth costal cartilages and corresponding approximately to the line of the transverse colon. The tenth cartilage has a distinct tip and plays over the ninth cartilage, producing a peculiar crepitus (Labbé).

If the incision is median, it passes between the recti muscles; if lateral and vertical, it is made through the rectus or along its outer edge; if oblique, through the rectus and the external and internal oblique and transversalis. The terminal branches of either the superior or deep epigastric artery may be divided, or the latter vessel itself if the vertical incision is prolonged downward. As the blood-supply of the stomach comes from three distinct sources—the gastric, hepatic, and splenic arteries—and the anastomoses are very numerous, the nutrition of the flaps, even after extensive resection, is usually maintained, in the absence of infection or of cardio-vascular disease. On the contrary, in operations on the intestines the greatest care must be exercised in dealing with the mesentery to preserve the vitality of the gut.

Upon exposing the stomach, it is well to bear in mind its oblique position and the facts that the pylorus is the only part that is really transverse, that three-fourths of the stomach are to the left of the middle line, that the upper part of the cardia is an inch above the level of the lower end of the œsophagus, and that the larger part of the greater curvature is directed to the left and of the lesser curvature to the right. According to Meinert, the pylorus lies behind the intersection of a transverse horizontal line drawn through the tip of the xiphoid cartilage with the right costal border; while the lower curvature, beginning at the latter point, crosses the mid-line and ascends, describing a half-circle around an antero-posterior horizontal line drawn through the xiphoid tip.

The relations of the stomach in general have been described (page 1619). The transverse colon—especially in cases of œsophageal stricture in which the stomach is contracted and rests far back and well up under the diaphragm—may present itself, and has been mistaken for the stomach. The gut, however, is thinner, not so

pinkish, and the longitudinal band, the sacculations, and the epiploic appendages on its lower aspect may be seen. If any doubt exists, the under surface of the left lobe of the liver should be followed up by the finger to the transverse fissure and then down on the gastro-hepatic omentum to the lesser curvature of the stomach. The dependent greater omentum and the gastro-epiploic artery on the greater curvature aid in the recognition of the stomach.

In *gastrotomy*—as for foreign body, for exploration, or for retrograde dilatation of the œsophagus—the incision may be vertical and midway between the two curvatures to minimize the hemorrhage (*vide supra*).

In *gastrostomy*—the establishment, for purposes of feeding, of a direct communication between the surface of the body and the stomach cavity—the abdominal incision may be oblique, parallel to the left costal cartilages, and 2.5 cm. (1 in.) from them, or vertical down to the left rectus, the fibres of which may be separated without division. In either case a part of the anterior wall of the stomach, made conical by traction, is brought out, carried upward beneath a bridge of skin, and fixed to the margins of a second opening over the costal cartilages. Various modifications are employed, all with the idea of securing a valvular or sphincteric condition in or about the orifice so as to prevent leakage of the stomach contents.

In *pyloroplasty*—applicable to simple hypertrophic stenosis or cicatricial stricture—an incision is made from the stomach to the duodenum through the pylorus and parallel to the long axis of the tract at that point. Its borders are then separated as widely as possible so that their mid-points become the ends of the opening, the edges of which are then sutured together in this position, materially widening the lumen of the canal.

In *pylorectomy* or *gastrectomy* large portions of the stomach, or the whole organ, are excised for malignant disease; in the former the omental connections of the pylorus must be severed and the right gastro-epiploic, the pyloric, and the gastro-duodenal arteries divided; in the latter, in addition, the pneumogastric nerves below the diaphragm and many more vascular trunks.

Partial gastrectomies, as for the excision of a nodular carcinoma or of a gastric ulcer, are much less serious. Division of the gastro-hepatic omentum, which holds the stomach up under the costal margins, will facilitate the freeing of the pylorus and lesser curvature and permit of ready access to the lesser peritoneal cavity. The gastro-colic omentum attached to the region of disease can then be made tense by the fingers passed behind and beneath the pylorus and can be ligated and divided (Mayo).

In *gastro-enterostomy*—as a palliative in cancerous pyloric stenosis or for the treatment of gastric ulcer—the intestinal canal (usually that of the jejunum, as the highest movable portion of the small intestine) is made directly continuous with the stomach cavity by the establishment of a permanent fistula between the two. The posterior wall of the stomach is now usually selected because of its nearness to the jejunum. It may be reached through the transverse mesocolon, the greater omentum with the transverse colon having been turned upward; or the gastro-colic omentum may be torn through or divided.

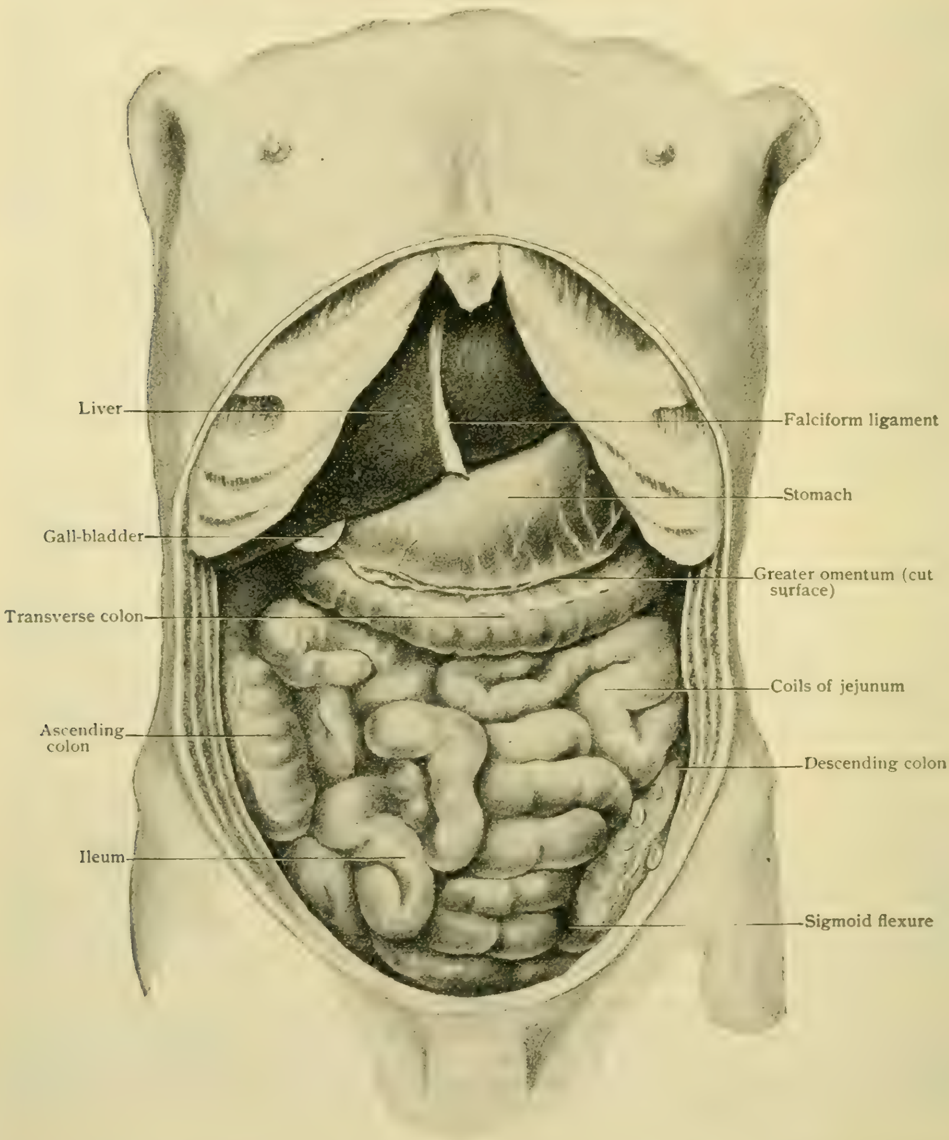
Gastroplasty (analogous to pyloroplasty) has been done in cases of hour-glass stomach following cicatricial contraction after gastric ulcer. Occasionally in these cases the constricting band has been mistaken for a thickened, contracted pylorus. Adhesions sometimes connect the constrictions with neighboring parts, as with the right rectus muscle (Elder) or the liver (Childe).

THE SMALL INTESTINE.

The stomach is followed by the long and complicated tube of the small intestine, divided into the *duodenum* and the *jejuno-ileum*. According to Treves, the average length in the male is 6.8 m. (22 ft. 6 in.) and in the female nearly 15 cm. (6 in.) more. This excess, however, would probably not be confirmed by a larger series. In the male the extremes were 9.7 m. (31 ft. 10 in.) and 4.7 m. (15 ft. 6 in.), in the female 8.9 m. (29 ft. 4 in.) and 5.7 m. (18 ft. 10 in.). The outer wall of the tube is regular, without sharp folds or sacculations, beyond the duodenum. The

circumference is greatest in the duodenum (not always at the same point), beyond which it gradually decreases, the diameter of the gut at its lower end being nearly one-third smaller than at the beginning. Since certain structural features are common to the entire small intestine, it will be convenient to consider these in this place, further details being given with the descriptions of the special parts.

FIG. 1383.



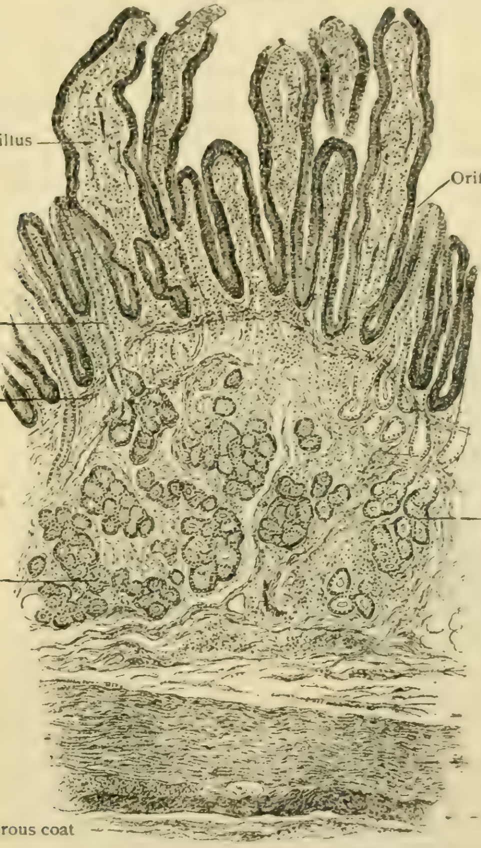
Abdominal organs of formalin subject. Stomach was unusually large, giving an exaggerated impression of its transverse position.

Structure.—The small intestine, as other parts of the alimentary tube below the diaphragm, consists of four coats, the *mucous*, the *submucous*, the *muscular*, and the *serous*.

The **mucous coat,** in addition to the glandular structures, possesses folds and villi that not only greatly increase its surface, but also contribute peculiarities which aid in differentiating between typical portions taken from various regions. The

epithelium covering the free surface consists of a single layer of cylindrical cells which exhibit a striated cuticular border next the intestinal lumen. This border lacks stability, and is resolvable into minute prismatic rods, placed vertically and probably continuous with the spongioplastic threads within the body of the cell. In many places, especially over the villi, mucus producing goblet-cells share the free surface with the ordinary epithelial elements. Between the latter migratory leucocytes are always to be seen. The *stroma* or tunica propria of the mucous coat resembles lymphoid tissue, being composed of a connective-tissue reticulum containing numerous small round cells similar to lymphocytes. This stroma fills the spaces between the glands and forms the core of the villi over which the epithelium stretches. The deep-

FIG. 1384.



Transverse section of small intestine (lower part of duodenum), showing general arrangement of coats. × 90.

est part of the mucous coat is occupied by a well-marked *muscularis mucosæ*, in which an inner circular and an outer longitudinal layer are distinguishable.

The **villi** are minute projections of the mucous surface, barely visible to the unaided eye, the presence of which imparts the characteristic velvety appearance to the inner surface of the small intestine. Although found throughout the latter, from the pylorus to the ileo-colic valve, they are most numerous (from 20–40 to the sq. mm.) in the duodenum and jejunum and less frequent (from 15–30 to the sq. mm.) in the ileum. In the duodenum they appear immediately beyond the pylorus, but reach their best development in the second part, where they measure from .2–.5 mm. in height and from .3–1 mm. in breadth; they are, therefore, here low and broad. In the jejunum the villi are conical and somewhat laterally compressed, while in the ileum their shape is cylindrical, filiform, or wedge-like, their length and breadth being from .5–1 mm. and from .2–.4 mm. respectively. The villi are projections of

the mucous coat alone, and consist of a framework of the lymphoid stroma-tissue, covered by columnar epithelium, which supports the absorbent vessel and the blood-vessels, together with involuntary muscle. The reticular tissue constituting the villus is condensed at the periphery, the existence of a definite limiting membrane being assumed by some (J. Schaffer, Spalteholz, Ebner). Each villus is supplied by from one to three small arteries, derived from the vessels of the submucosa, which break up into a capillary net-work lying beneath the peripheral layer of the stroma. The blood is returned usually by a single vein which, beginning at the summit by the confluence of capillaries, traverses the central parts of the villus and becomes tributary to the larger venous stems within the submucous coat.

The *absorbent*, *chyle-vessel*, or *lacteal*, as the lymph-vessel occupying the villus is variously termed, lies near the centre of the projection, surrounded by the muscular tissue and the blood-capillaries. While the slender cylindrical villi contain only a single lymphatic, from .025–.035 mm. in diameter, those of broader form often contain two, three, or even more such vessels, which may communicate by cross-channels. Their walls consist of a single layer of endothelial plates. The muscular tissue within the villus, prolonged from the muscularis mucosæ, forms a delicate layer of slender fibre-cells, longitudinally disposed, which surround the central chyle-vessel. Contractions of this tissue shorten the villus and aid in propelling the emulsified contents of the lymphatic.

FIG. 1385.

Surface view of mucous membrane of jejunum, showing villi and orifices of glands. × 12.

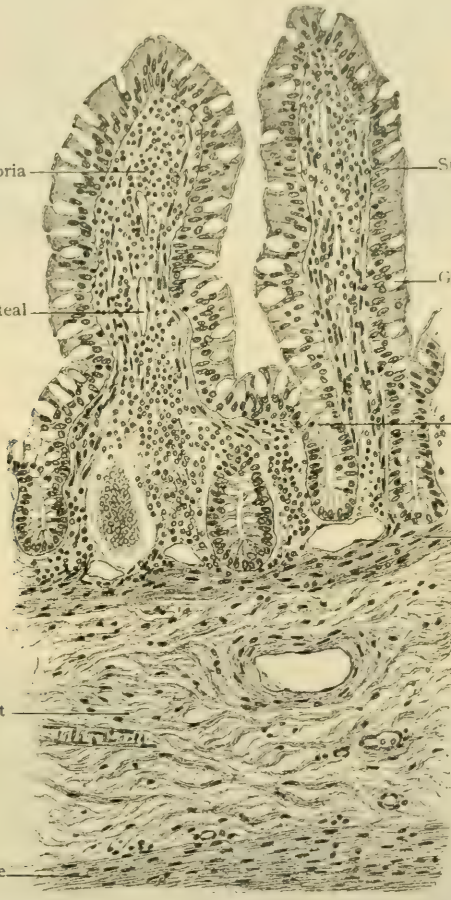
The presence of numerous oil-droplets of considerable size within the epithelial cells, as well as stroma, of the villi during certain stages of digestion has caused much speculation as to their mode of entrance. On histological grounds there is good reason for assuming that a large part of the fat particles seen within the tissues gains access in a condition either of solubility, saponification, or exceedingly fine molecular subdivision, the accumulations observed within the tissues being due to secondary change (Ebner).

The **valvulæ conniventes** (**plicae circulares**), within the duodenum and the jejuno-ileum, model the mucous coat and greatly increase its secreting and absorbant surface; they also retard the passage of the intestinal contents, thereby facilitating the digestive processes. These transverse folds begin in the second part of the duodenum and consist of duplicatures which involve not only the entire thickness of the mucosa, but contain a central supporting projection of the submucous coat; hence, while they may fall on their sides, they cannot, as a rule, be effaced by distention. The height of the folds, where well developed, rarely much exceeds 1 cm., and towards the lower part of the jejunum is much less. The majority of the valves do not extend more than two-thirds or three-fourths of the circumference of the gut; exceptionally, however, circular and spiral ones describe two or three complete turns. Their ends, usually simple, may be bifurcated. Smaller folds, more or less effaceable, run obliquely as offshoots from the larger ones. The valves are much larger on the attached side of the gut than on the free one; in the latter position they may be entirely absent in localities in which the folds are feebly developed. Succeeding the first part of the duodenum, the valvulæ conniventes are very numerous and large, and so near together that in falling over any fold would come in contact with the next one. Descending the small intestine, they gradually become smaller and farther apart, so that the distance between them considerably exceeds their height. They also become more effaceable, and finally very much so. In

this respect much variation exists, which partially accounts for the differences found at the lower part of the small intestine, where often the valves are absent, while at other times they are well marked. Sernoff[1] found in subjects treated with chromic acid injections that the valves were as frequent in one part of the small intestine as another, but less regularly transverse in the lower. He observed places without valves, usually at the convexity of folds, in all parts of the gut, and regards them as largely dependent upon the condition of the muscular coat. It is certain, however, that the valves of the upper part of the intestine are independent of this influence; those in the lower portion, perhaps, may be produced in such manner.

Glands.—The structures within the alimentary tube to which the term "glands" has been applied include two entirely different groups, the *true* and the *false* glands.

FIG. 1386.



Transverse section of small intestine (jejunum), showing villi cut lengthwise. × 150.

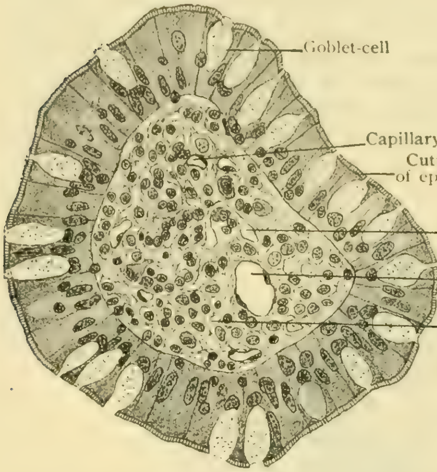
The former are really secreting organs,—the glands of Lieberkühn and of Brunner; the latter are more or less extensive accumulations of adenoid tissue, and are appropriately spoken of as lymphatic nodules or follicles.

The **glands of Lieberkühn** are simple tubular depressions which are found not only throughout the entire small intestine, but in the large as well. They are very closely set, narrow, and extend the thickness of the mucous coat as far as its muscular layer. In length they vary from .3–.4 mm. and in diameter from .060–.080 mm. The fundus of the glands is slightly expanded and in exceptional cases divided. The lining of the crypts rests upon a delicate basement membrane, and consists of a single

[1] Internat. Monatsschrift f. Anat. u. Physiol., Bd. xi., 1894.

layer of columnar cells directly continuous with those covering the villi. They differ from the latter in being only about half so high (.018 mm.) and in not presenting the characteristic cuticular border. This last gradually disappears as the cells dip into

FIG. 1387.



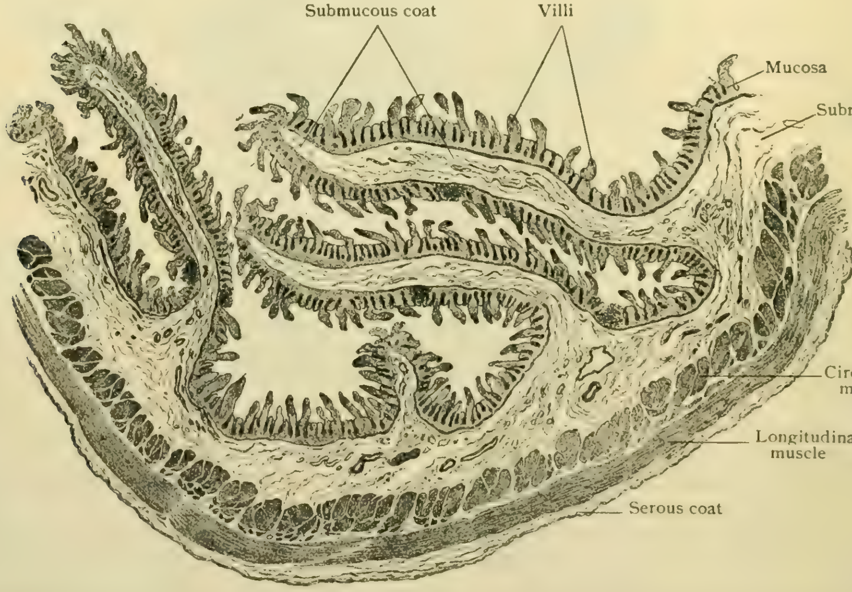
Transverse section of single intestinal villus, showing relation of epithelium, stroma, and vessels. × 350.

FIG. 1388.

Surface view of mucous membrane from end of jejunum showing valvulæ conniventes. Stippled appearance is due to villi covering folds. Natural size.

the follicles to become the lining of the glands. Under low magnification the surface of the small intestine presents numerous pits, the orifices of the glands, which almost entirely fill the spaces between the bases of the villi; with the exception of

FIG. 1389.



Longitudinal section of duodenum; valvulæ conniventes cut across, showing relation of these folds to villi. × 15.

the areas immediately over the lymph-nodules, where they are partially pushed aside, these glands are present in all parts of the intestine. They, however, take no part in absorption, never containing fatty particles during periods in which such substances

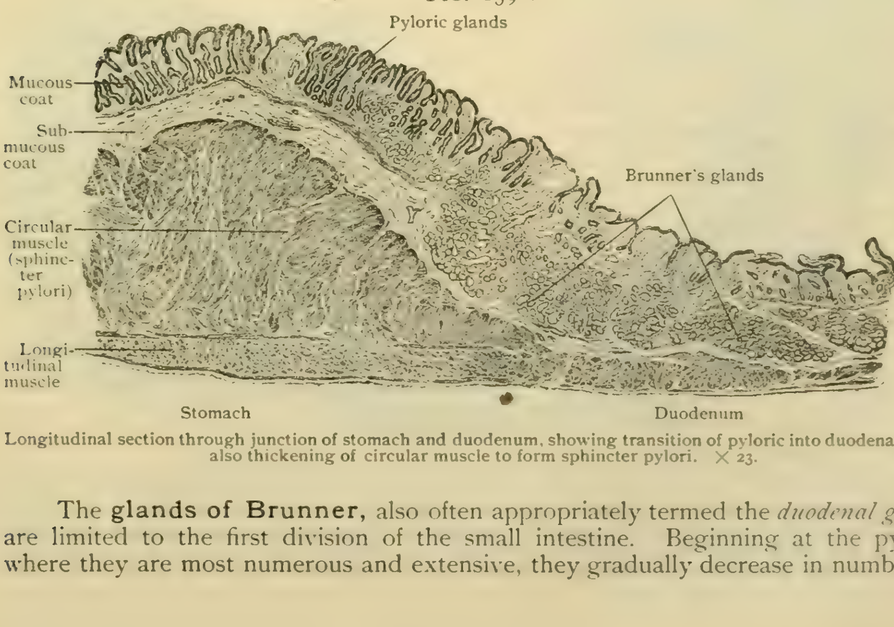
are seen within the epithelium of the villi. It is worthy of note that even in the adult mitotic figures are frequently observed within the cells lining Lieberkühn's glands, although such evidences of cell-division are rare among the elements covering the

FIG. 1390.

Longitudinal section of duodenum, showing Brunner's and Lieberkühn's glands, villi, and lymph-node. × 100.

villi. The lining of these crypts is an active source for the regeneration of the intestinal epithelium. Migratory leucocytes are also present. Small groups of granular elements, the *cells of Paneth*, occur within the crypts, constantly in the ileum and uncertainly in the other parts of the small intestine. Their significance is undetermined.

FIG. 1391.

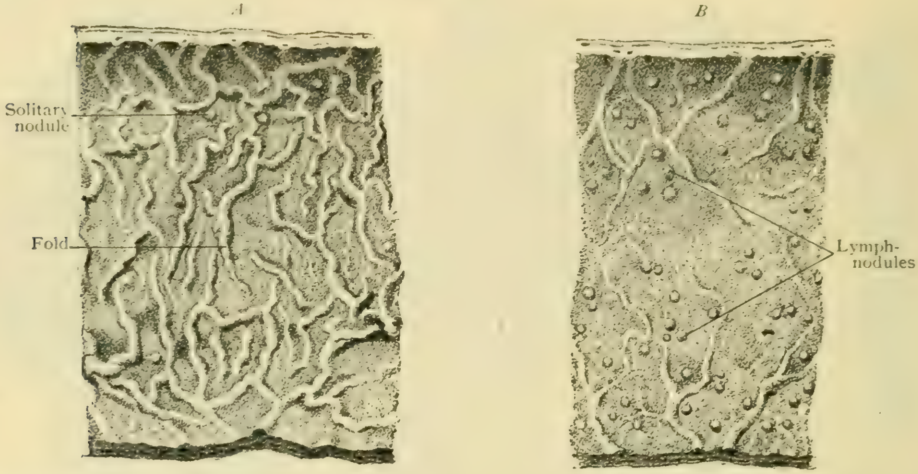


Longitudinal section through junction of stomach and duodenum, showing transition of pyloric into duodenal glands; also thickening of circular muscle to form sphincter pylori. × 23.

The **glands of Brunner**, also often appropriately termed the *duodenal glands*, are limited to the first division of the small intestine. Beginning at the pylorus, where they are most numerous and extensive, they gradually decrease in number and

size, being sparingly present beyond the opening of the bile-duct and entirely wanting at the lower end of the duodenum. These glands are direct continuations of the pyloric glands of the stomach, with which they agree in all essential details. While, however, their gastric representatives are confined to the mucous coat,

FIG. 1392.

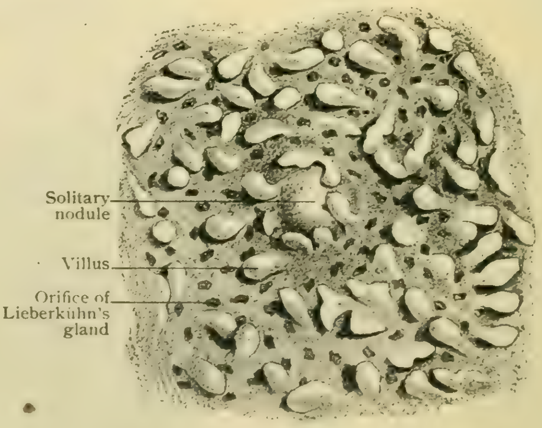


Surface views of mucous membrane from upper (*A*) and lower (*B*) part of ileum, showing folds and solitary lymph-nodules. The velvety appearance is due to the villi. Natural size.

Brunner's glands chiefly occupy the submucosa, the migration taking place at the pyloric ring (Fig. 1391). The duodenum, therefore, possesses a double layer of true glands,—those of Lieberkühn within the mucous coat, beneath which, in the submucosa, lie those of Brunner. The individual glands, tubo-alveolar in type, form somewhat flattened spherical or polygonal masses, measuring from .5–1 mm., which consist of richly branched tubules, ending in dilatations. Their excretory ducts pierce the mucous coat and open either directly on the free surface or into the crypts of Lieberkühn. While narrower than that of the alveoli, the epithelium of the ducts is the same as that found in the deeper parts of the tubules. The clear, low columnar cells lining the duodenal glands are probably identical in nature with those of the pyloric glands, the variations in size and granularity sometimes observed depending upon differences in functional condition. Brunner's glands correspond to the pure mucous type (Bensley).

Lymph - Nodules. — The lymphatic tissue within the intestinal tube occurs in the form of circumscribed nodules, which may remain isolated, as the *solitary nodules*, or be collected into considerable masses, as *Peyer's patches*.

FIG. 1393.



Surface view of mucous membrane of ileum. × 10.

The **solitary nodules** vary greatly in number and size, sometimes being present in profusion in all parts of the small intestine, at other times almost wanting; they are usually scanty in the upper and more numerous in the middle and lower parts. They appear as small whitish elevations, spherical or pyriform in shape, and from .2–2 or even 3 mm. in diameter, at the bottom of small pits.

The walls of the latter, however, are so closely applied to the nodules that the existence of the pit is not at first evident. Villi are wanting over the prominence of the nodules; likewise the glands of Lieberkühn, the orifices of which are arranged as a wreath around the nodules. The latter are found as much on one side of the intestinal tube as on the other.

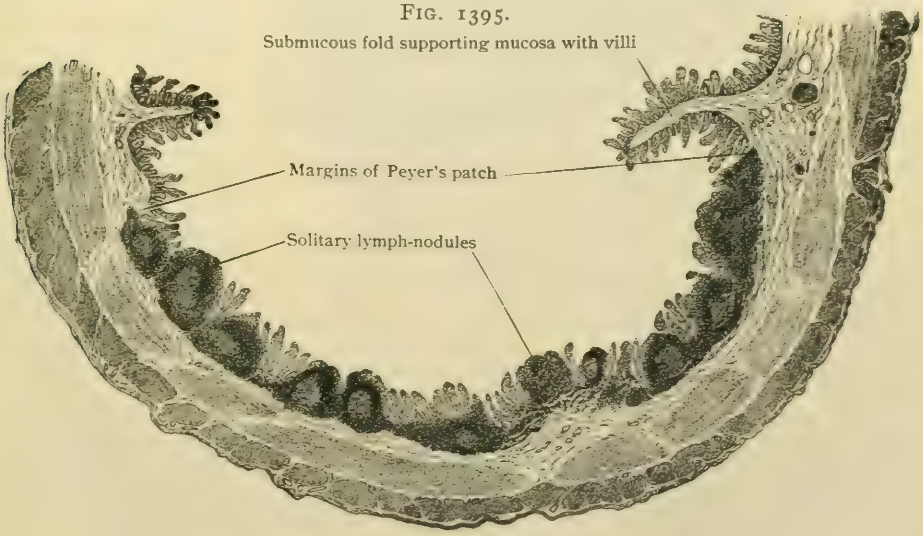
FIG. 1394.

Surface view of portion of mucous membrane of ileum, showing Peyer's patch and solitary lymph-nodules. Natural size.

In structure the solitary nodules correspond to similar lymph-nodes in other localities, consisting of a capsule of denser tissue enclosing the delicate adenoid reticulum which supports the characteristic lymphocytes within its meshes. Within the larger nodules germ-centres, spherical or ellipsoidal in form, occupy the middle of the nodules; the germ-centres are, however, not constant, being present, as a rule, in young subjects, but often absent in old individuals. A generous blood-supply is provided by the rich net-work of small vessels which surrounds the nodules; fine capillaries penetrate into their interior, but usually do not reach the centre of the nodes. Definite lymph-paths have not been demonstrated within the nodules, although a plexus of lymphatics surrounds their exterior (Teichmann).

Peyer's patches (**noduli lymphatici aggregati**) are collections of solitary lymph-nodules, the individual follicles being blended by intervening adenoid tissue. They are seen in the lower half of the small intestine, especially near the lower end (ileum); exceptionally they are found in the upper part of the jejunum in the vicinity of the duodenum. The patches appear as slightly raised, elongated ovals,

FIG. 1395.

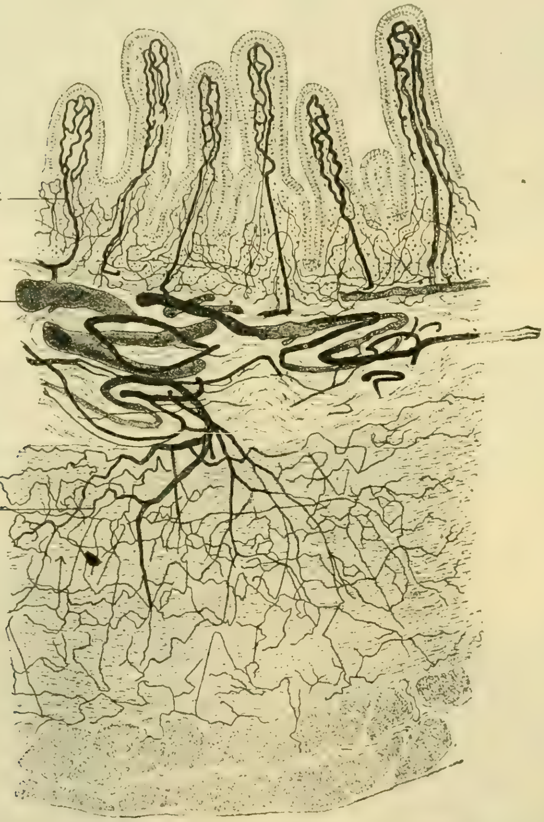


Transverse section of ileum, showing Peyer's patch cut across. × 10.

always on the side of the intestine opposite to the attachment of the mesentery. Their usual number is about thirty, although as few as eighteen and as many as eighty-one have been counted (Sappey). In length they ordinarily measure from

1–4 cm. and in breadth from 6–16 mm.; exceptionally their length may reach 10 cm. or more. In general the size of the patches increases as the termination of the ileum is approached. Each patch contains usually from twenty to thirty lymph-nodules, although as many as sixty or less than ten may be present. The individual nodules are commonly somewhat pear-shaped, and when well developed occupy both the mucous and submucous coats, their smaller end almost reaching the epithelium and their base the muscular tunic. The free surface of the patches is modelled by minute pits, from .4–2 mm. in diameter, and low intervening ridges; the former mark the positions of the component nodules, the latter that of the blending internodular tissue. The villi and the crypts of Lieberkühn are present over the areas between the pits, although less developed than beyond the patch. In their minute structure the lymph-nodes composing the patch closely correspond to the solitary nodules, the aggregated nodules being blended into a continuous mass by the less dense adenoid tissue which fills the spaces between the individual follicles. The entire patch is defined from the surrounding structures by an imperfect capsule.

Fig. 1396.



Transverse section of injected small intestine, showing general distribution. × 55.

The **submucous coat** is lax, but not enough so to allow the displacement of the valvulæ conniventes, except at the lower part. As in other segments of the intestinal tube, the submucosa contains blood- and lymph-vessels of considerable size and the nerve-plexus of Meissner.

The **muscular coat,** about .4 mm. thick, consists of an outer longitudinal and an inner circular layer. The latter is some two or three times as thick as the former and is pretty regularly arranged. The thin longitudinal layer, thickest at the free border, is often imperfect, especially at the attachment of the mesentery. The entire muscular coat diminishes in thickness from above downward.

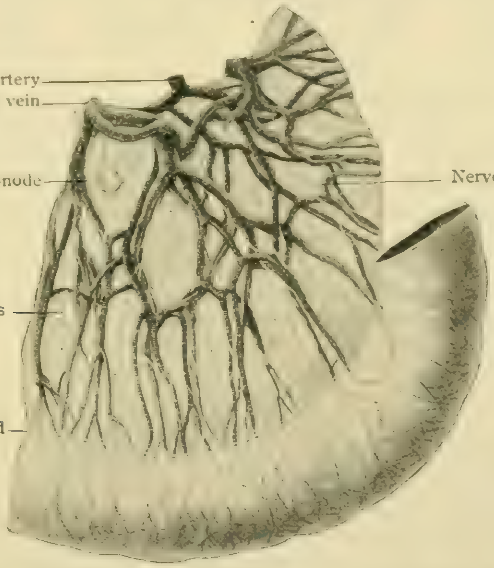
The **serous coat,** with the exception of that of the duodenum, completely surrounds the gut except at the line of attachment of the mesentery, where the two layers of peritoneum diverge, leaving an uncovered space between them just large enough for the passage of the vessels and nerves. Its structure resembles that of the serous coat of the stomach (page 1627), and includes the fibro-elastic stroma covered with the endothelium.

The **blood-vessels** supplying the small intestine are distributed to the walls of the tube in a manner closely agreeing with the arrangement found in the stomach (page 1627); the same general plan applies also to the large intestine. The *arteries*, which pass to the intestine between the peritoneal folds constituting the mesentery,

after supplying the serous coat, penetrate the muscular tunic to reach the submucosa. Within the latter branches arise which, in conjunction with those directly given off during the passage through the muscular coat, supply the muscular tissue. The more important and larger arterial twigs from the vessels of the submucosa enter the mucous coat, in which some break up into capillaries forming net-works surrounding the gland-tubules and supplying the muscular and stroma tissue; others pass directly towards the villi, which they enter and supply by capillary net-works occupying the periphery of the projections. The *veins* of the intestinal walls commence within the mucosa beneath the epithelium and, gradually enlarging as they descend, become tributary to the larger veins within the submucosa. The latter follow the arteries in their passage through the muscular tunic, uniting to form the larger emergent venous channels which accompany the arterial trunks between the peritoneal folds.

The **lymphatics** of the small intestine, long known as the *lacteals* from their conspicuous milky appearance when filled with emulsified fat during certain stages of digestion, begin as the absorbent or chyle-vessels within the villi. In addition to these, radicles commence within the stroma-tissue of the mucosa, in which the lymphatics form a plexus in the plane of the muscularis mucosæ. From the latter tributaries descend to the larger plexus within the submucosa, which is characterized by channels of irregular form and calibre containing numerous valves. The emergent lymphatics form larger vessels within the serous coat, which pass to the lymph-nodes situated between the peritoneal layers; from these smaller lymphatic masses efferent vessels converge to the larger mesenteric lymph-nodes at the root of the mesentery.

FIG. 1397.



Portion of small intestine and mesentery, showing arteries, nerves, and lymphatics; latter have been injected with quicksilver. Anterior layer of mesentery has been removed.

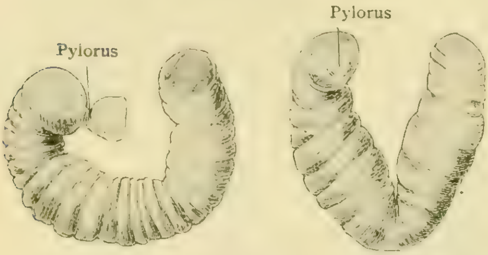
The **nerves** supplying the small intestine, derived from the solar plexus and consisting of both medullated and non-medullated fibres from the cerebro-spinal and sympathetic systems, closely follow the disposition observed in the stomach (page 1628). After piercing the other longitudinal layer they form the intramuscular *plexus of Auerbach*, consisting of both varieties of fibres and microscopic sympathetic ganglia. The nerves continue obliquely through the circular muscular layer and form within the submucous coat the *plexus of Meissner*. From this plexus non-medullated fibres enter the mucous coat and are distributed as periglandular and subepithelial net-works, as well as supplying the muscular tissue, in which, according to Berkley, additional special end-organs exist. Within the villi a rich plexus of non-medullated

fibres has been demonstrated from which terminal fibrillæ are distributed to the muscular tissue and vessels, as well as beneath the epithelium.

THE DUODENUM.

The duodenum at an early stage is a loop with a forward convexity passing from the pylorus back to the spine. It enlarges into nearly a circle and turns onto its right side, its termination remaining attached below the cœliac axis to the top of the second lumbar vertebra. The part immediately following the stomach remains free, but a little farther back it is suspended from the liver by the *duodeno-hepatic ligament*, which is the free border of the lesser omentum, containing the portal vein, the hepatic artery, and the bile-duct with the connective tissue about them. This structure is strong enough to deserve to be called a ligament. The duodenum is therefore nearly a ring suspended at two points, one near the beginning and the other (to be described later) at the end. In the adult the shape is more or less a modification of this imperfect ring. When relaxed and empty it often nearly retains this shape. When distended by inflation or injection it usually shows four parts. The *first*, some 5 cm. (2 in.) long, runs backward from the pylorus, slightly upward and to the right. The beginning of this portion is movable ; later the part is fixed by the structures just mentioned. The other divisions of the duodenum are disposed so as to form a U. The *second* part descends along the right of the spine to the fourth lumbar vertebra. The *third* runs forward and to the left, with a slight rise. The *fourth* ascends on the spine to the upper part of the second lumbar vertebra, where, after a sharp bend,—the *duodeno-jejunal flexure*,—it becomes the jejunum.

FIG. 1398.



Casts of duodenum, showing U- and V-forms.

The next most common form is the V-shaped, of which there are two varieties. In the more usual one the second part descends, as in the preceding form, and the third and fourth are represented by one which ascends obliquely to the termination. The less frequent variety has the second part inclining forward and to the left as it descends, so that the V is more symmetrical. A modification of the U-form, which we have called the C-shaped, is characterized by a very short second part, so that the first and third parts are almost in contact. From seventy observations[1] on adults (including one girl of fourteen), mostly by means of casts, we find the following forms :

	Male.	Female.	Sex not noted.
U-shaped	10	3	9
V-shaped	9	9	3
Ring-shaped	2	2	..
Indeterminate	7	3	1
C-shaped	5	..	..
Not to be classified	5	..	2
	38	17	15

By "indeterminate" is understood those that might be placed in any two of the U, V, or C types, according to the classifier. Those marked "not to be classified" are absolutely irregular. The V-shape is particularly common in women and the irregular forms in men. It should be noted that a very large part of the duodenum lies in an essentially antero-posterior plane,—namely, the first, second, and a considerable portion of the third part, the organ being moulded on the spinal column. The length of the whole duodenum and of its parts is so variable that a statement can be only general. The first part is, according to Testut, 5 cm., the second 8 cm., the third 6 cm., and the fourth 7 cm., the total length of the duodenum being 26 cm., or about 10 in. The circumference varies greatly in different bodies. The fourth part is the smallest. The second increases in size as it descends, and the largest point is in either the second or third. The two largest circumferences that we have measured were in the second part. We are satisfied that the size of some immense duodena is in no way due to artificial distention ; to what extent it is pathological is uncertain.

[1] Journal of Anatomy and Physiology, vol. xxxi., 1897.

The **first part** is often egg-shaped, narrowing at the ends. Its main direction is backward, slightly upward and to the right, to reach the first lumbar vertebra; but, as it is movable, its direction is somewhat variable. The gut rests above against the quadrate lobe of the liver and the neck of the gall-bladder, behind which it is free, forming the lower border of the foramen of Winslow. The left side looks into the lesser peritoneal cavity, and is crossed near the back by the common bile-duct. The right side is chiefly against the liver and gall-bladder; otherwise it is in contact, as is the lower side, with coils of the small intestine. The lower side, moreover, rests on the head of the pancreas.

The **second part** descends vertically, forming an acute angle with the first. It is bent so sharply that a fold of the entire thickness often projects into the gut. It lies on the right side of the vertebral bodies beside the vena cava, and behind rests on the right suprarenal capsule and kidney, being in contact also with the pelvis of the latter, the renal vein, and the beginning of the ureter. The precise relations with the right kidney are uncertain, owing to the variations both of that organ and of the duodenum. It lies on the right against the ascending colon and on the left against the head of the pancreas, which may overlap it in front. The bile-duct runs along the left side and passes obliquely through the intestinal wall, to empty, in conjunction with the pancreatic duct, some 10 cm. from the pylorus.

From observations on fifty-four adult duodena (thirty-eight male, sixteen female) we have found that in the great majority of duodena of both sexes the lowest point is opposite the fourth lumbar vertebra or the disk above or below it. In about one-quarter of the cases it is opposite the third, and only some half dozen times opposite the fifth, of which cases some were probably pathological. The mean of the female duodenum, in which sex the V-shape is most frequent, is a little lower than that of the male, but not strikingly so. The angle between the second and the third parts in the U-form is rather less sharp than that between the first and the second.

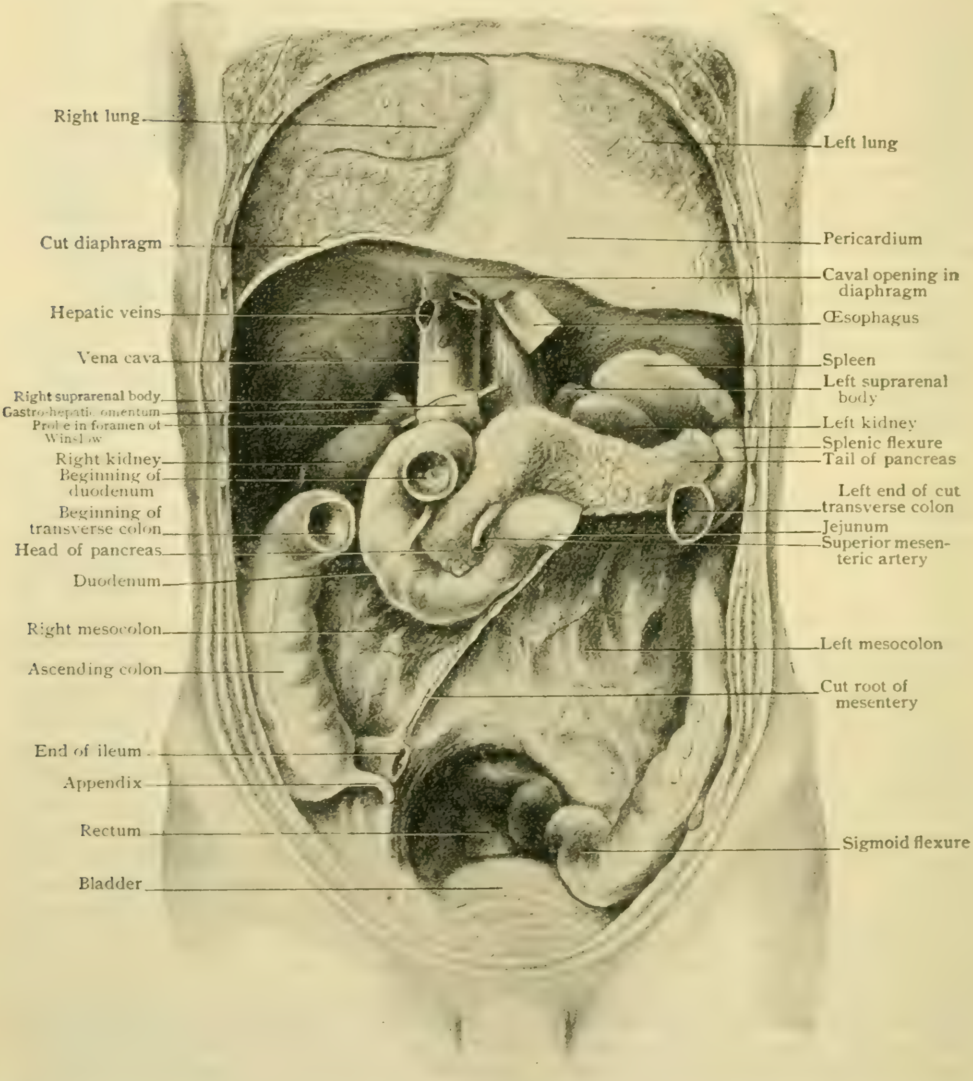
The **third part** curls around the spinal column, passing forward to its front and then to the left with a slight ascent till it reaches the aorta. It crosses the vena cava and has the pancreas above it, which, with the first and second parts, it tends to enclose. The head of the pancreas may, however, more or less overlap the third part as it does the second, and also insinuate itself behind it. In less than one-quarter of the cases the third part crosses the aorta, its course being more transverse than the one just described. It may be connected to the aorta by areolar tissue or, especially if it run only just beyond the aorta, a fold of peritoneum may intervene.

The **fourth part** usually begins at an obtuse angle with the third, and ascends on the front of the spine to the top of the second lumbar vertebra. In this course it overlaps the aorta and usually ends either directly over it or just at its left. In fifty-four observations the duodenum was on the right of the aorta until just before its final flexure twenty-six times. It was wholly on the right of the aorta six times. The fourth part lay in front of the aorta eleven times and the third part actually crossed it eleven times. It is clear from the above that it is exceptional for the duodenum to reach the left kidney and ureter, but it may do so when it really crosses the aorta. The tail of the pancreas is behind it, as is usually a part of the left suprarenal capsule. The head of the pancreas may be so developed as to overlap it, but this is rare. The mesentery of the small intestine usually rises above on its front surface and gradually crosses it to the right. It may be very nearly surrounded by peritoneum, or the posterior surface may be without it. Sometimes, although rarely, the last part stops short of the second lumbar. In the V-shaped duodenum the third and fourth parts are in one. This form evidently is wholly to the right of the aorta, except, perhaps, the very end. It sometimes ascends along the right side of the right iliac artery, and then on the right or front of the aorta. The duodenum ends in a sharp turn, the *duodeno-jejunal flexure*. The very top of the gut at the bend is suspended from the left crus of the diaphragm and from the areolar tissue about the cœliac axis by the *duodenal suspensory muscle of Treitz*, a small triangular band of muscular and fibrous tissue, which reaches the gut where it is uncovered by peritoneum, and is said to join the layer of longitudinal muscular fibres. This band and the *duodeno-hepatic ligament* hold all the duodenum after the very beginning suspended and fixed so that only the beginning is movable. It is further secured by

the retro-peritoneal connective tissue and by the peritoneal reflections. The shape allows the food from the stomach as well as the fluid poured into it from the liver and pancreas to accumulate and thus to act as an S-trap to prevent the passage of gases from the intestine into the stomach. At the same time the great development of the plicæ tends to retard the passage of the food.

Peritoneal Relations.—The peritoneum of the front and back of the stomach is continued along the right and left sides of the first part of the duodenum respec-

FIG. 1399.



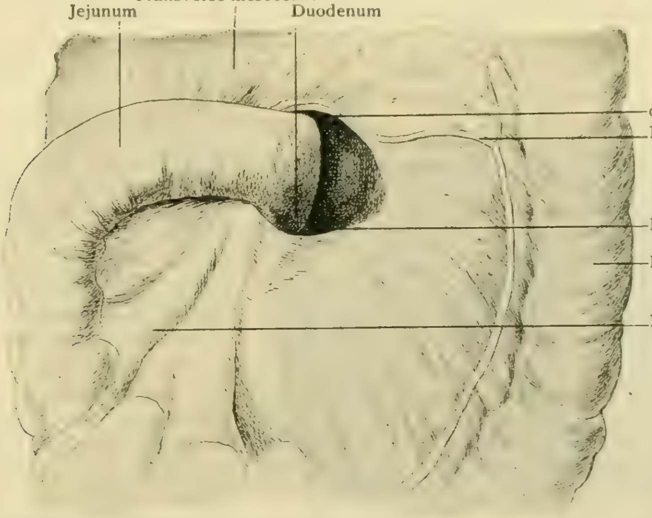
Abdomen of formalin subject; peritoneum partially dissected off, exposing organs *in situ* on posterior wall; transverse colon, mesocolon, mesentery, and jejuno-ileum removed.

tively. These layers meet above along the greater portion of the first part to form the lesser omentum, which ends posteriorly, as already stated, by forming the hepatico-duodenal ligament, consisting of the vessels entering the portal fissure of the liver with their enveloping connective tissue. The free edge where the peritoneum passes behind the ligament is on the inner side rather than above the gut. Just back of this

fold the upper surface of the first part of the duodenum is covered by peritoneum and forms the floor of the foramen of Winslow. The attachment of the greater omentum, which is continued from the greater curvature of the stomach onto the under side of the duodenum, passes along its inferior surface to the second part, where in the adult it has fused with the mesentery of the transverse colon. The peritoneum of the right side of the first part of the duodenum looks into the general peritoneal cavity and that of the left side into the lesser cavity.

The relations of the remainder of the duodeuum necessarily vary with the distention of the intestine; but it is correct to say that it lies behind the peritoneum, owing to the change into connective tissue subsequent to the fusion of the serous membrane of the right side of the duodenum and that of the posterior abdominal wall. Very often when the fourth part lies in front of the aorta a fold of peritoneum passes some distance in between them from the left; but this pocket disappears when the gut is distended. The pancreas, when it overlaps the second, third, or even the fourth part, more or less displaces the peritoneum. The duodenum is crossed by the attachment of the mesentery of the jejuno-ileum and by that of the transverse mesocolon. The series of changes by which this has occurred is dealt with under

FIG. 1400.



Duodeno-jejunal junction, showing duodenal fossæ; jejunum turned to the right.

Peritoneum (page 1742), the adult condition alone being here considered. The line of attachment of the transverse mesocolon crosses the second part of the duodenum a little below the deep flexure which on the front separates it from the first. The position of the line of attachment of the mesentery of the jejuno-ileum varies with the shape and position of the duodenum. Should the latter have its third part crossing the aorta, the attachment of the mesentery will cross the third part only, passing somewhat obliquely downward to the right. In the more usual arrangement, in which the fourth part of the duodenum either ends on the front of the aorta or crosses it only just before its termination, the line of attachment starts on the front of the fourth part or somewhat on the right of it and descends on more or less, sometimes on the whole length of this portion, or else lies just to the right of it and then crosses the third part. In the case of the V-shaped duodenum the mesentery runs down on or along the right of the oblique portion.

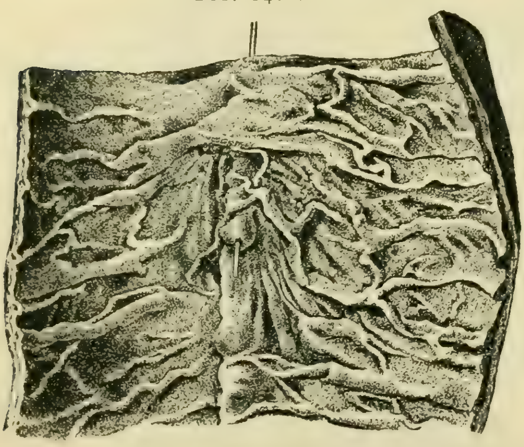
Duodeno-Jejunal Fossæ.—Several pockets formed by folds of peritoneum are found near the end of the duodenum in the greater cavity of the peritoneum. Some are vascular,—that is, containing a vessel at or near the edge of the fold,—while others are not. We have adopted the classification of Jonnesco, who describes five forms.

The *inferior duodenal fossa* (Fig. 1400) is the most common form, occurring, according to Jonnesco, in 75 per cent., and to Treves in 40 per cent. It is non-vascular, formed by a fold of peritoneum passing from the left of the fourth part of the duodenum to the posterior wall, with a free concave edge looking upward. The pocket extends down behind this fold for a variable distance. It may reach the fourth lumbar vertebra.

The *superior duodenal fossa* occurs in 50 per cent. This corresponds to the preceding, only it runs upward behind a fold, with a concave free edge looking downward, passing from the duodeno-jejunal flexure to the posterior wall on the left. The pocket is less deep than the preceding. It is usually vascular, the inferior mesenteric vein running in the fold, sometimes near its edge. These two fossæ frequently coexist, and the left ends of the folds may be continuous, so as to form a large C-shaped fold, open to the right, with a pocket under both the upper and the lower limbs. In this case the vein may be in the vertical part of the fold. An arterial arch, formed either by the ascending branch of the left colic artery or by the left branch of the middle colic, is often very close to the vein. Such a pouch may extend deeply under the fourth part of the duodenum.

The *mesocolic fossa*,[1] found in 20 per cent., and always alone, is a little pocket on the top of the duodeno-jejunal flexure under a fold from the posterior layer of the transverse mesocolon. When this membrane is reflected so as to show it, the fossa appears to run upward. The inferior mesenteric vein may be in the fold.

Fig. 1401.



Surface view of mucous membrane of duodenum ; entrance of bile and pancreatic ducts shown by probe, which lies in bile-duct. Papilla is surrounded by hood-like fold. Natural size.

The *paraduodenal fossa* is in the peritoneum of the posterior abdominal wall, less intimately connected with the gut than the others. It is a pocket formed by the superior branch of the left colic artery raising a fold of the peritoneum. The mouth of the pouch is to the right. It is not uncommon in the infant, rare in the adult.

The *retroduodenal fossa* is an uncommon pouch under the third and fourth parts of the duodenum, extending upward with the mouth below.

Interior of the Duodenum.—The mucous coat is smooth in the first part and overlies the glands of Brunner (page 1639), which lie chiefly within the submucosa and form a continuous layer for some 4 or 5 cm. ; beyond they are scattered for some distance farther. The villi are small at the beginning, but soon attain their complete size. The valvulæ conniventes are at first absent for about 4.5 cm., appearing at the end of the first part, and are almost at once large, near together, and non-effaceable. A very large one is formed by the folding in of the wall at the junction of the first and second parts ; beyond this the valves at once reach their greatest development. In the second part the *bile-papilla* is seen in the back part of the left or inner wall, from 8.5–10 cm. (about 3½–4 in.) beyond the pylorus, or rather below the middle, through which the common bile-duct and the duct of the pancreas pass to open by a common orifice. The papilla is almost always overhung by a valvular fold (Fig. 1401), and when non-distended is only some 5 mm. long. The accessory duct of the pancreas often opens 2 or 3 cm. above the main one through a much smaller and inconstant papilla. The submucous coat holds the mucous membrane pretty firmly in place, so that the folds are permanent.

[1] Jonnesco calls this also the *fossette duodeno-jejunale ;* but, although following him otherwise, we have retained duodenal as the generic name.

Blood-Vessels.—*Arteries.*—The duodenum, like the stomach, is attached to that part of the original mesentery through which the branches of the cœliac axis run. The stomach is supplied chiefly by the gastric and the splenic arteries, the duodenum by the hepatic with the help of a recurrent branch from the superior mesenteric. The hepatic artery gives off the pyloric, which sends some insignificant twigs to the beginning of the duodenum, and the gastro-duodenal, which runs on the left of the first part and sends off the superior pancreatico-duodenal, which passes downward and to the left in the concavity of the duodenum between it and the pancreas, lying rather on the front of the duodenum, of which it is the chief artery. The superior is met by the inferior pancreatico-duodenal artery, which arises from the right side of the superior mesenteric and descends along the right of the fourth part of the duodenum. The superior mesenteric distributes one or two small twigs to the very end of the duodenum.

FIG. 1402.

Abnormal form and course of duodenum. (*Schiefferdecker.*)

Veins.—The pyloric vein,—larger than the artery of the same name,—in conjunction with the superior pancreatico-duodenal, drains the greater part of the duodenum. They may open in common or separately into the portal vein, and are in direct connection with the inferior pancreatico-duodenal, which opens into the superior mesenteric vein.

The **lymphatics** pass to the pre-aortic lymph-nodes.

The **nerves** of the duodenum, as are those supplying other parts of the small intestine, are from the solar plexus.

Variations.—As already shown (page 1644), much variation exists in the shape of the duodenum; moreover, very extraordinary duodena sometimes occur. It is probable that these are generally due to an over-long duodenum, which, after having completed the usual course, describes one or more additional curves before reaching the duodeno-jejunal flexure. We have seen a case in which the end of the V almost touched the pylorus and then, mounting still higher, described a loop to the left behind the peritoneum. This occurred in a man with the sigmoid flexure and rectum on the right. These cases usually are associated with other errors of intestinal or peritoneal development. In the remarkable case of Schiefferdecker[1] (Fig. 1402) there was a mesenterium commune.

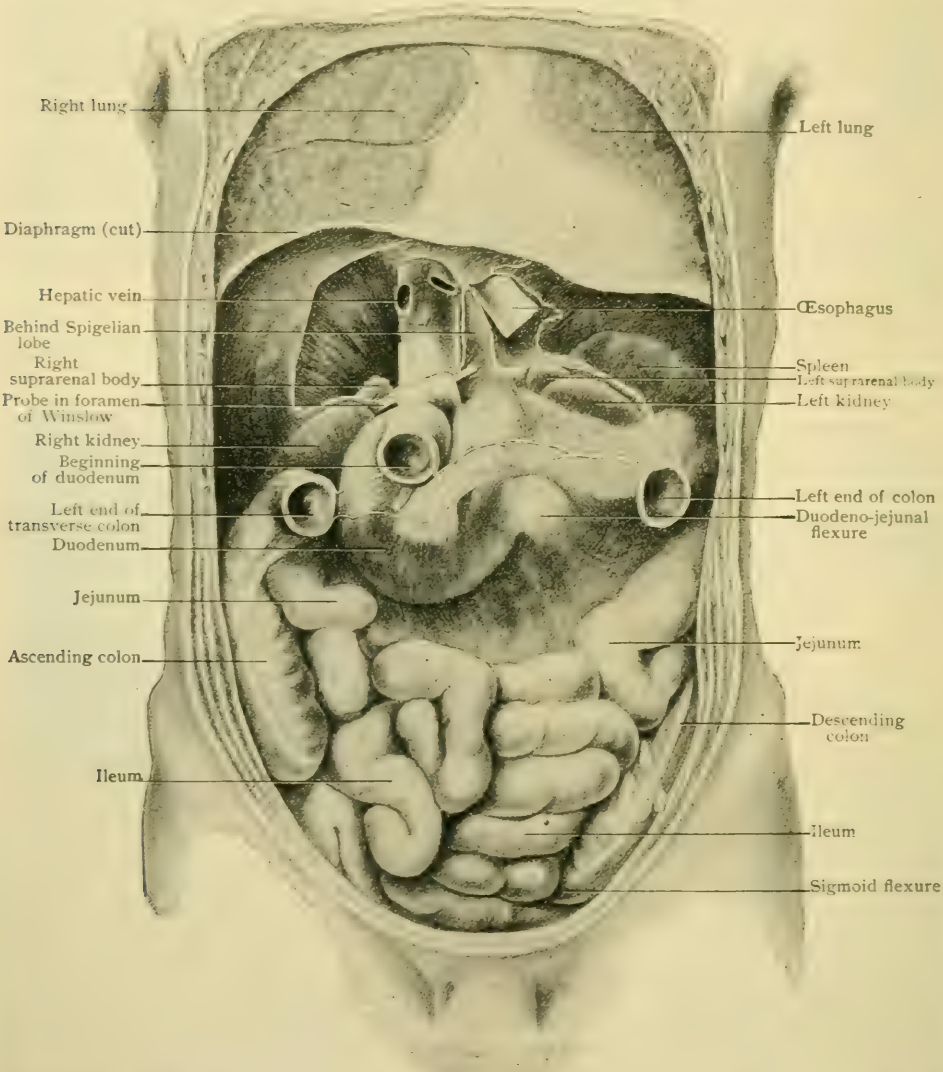
THE JEJUNO-ILEUM.

The jejuno-ileum includes the remainder of the small intestine, which, disposed in folds attached on one side to the mesentery, extends from the duodeno-jejunal fold to the cæcum, its length being, therefore, approximately 6.75 m. (nearly 22 ft.), of which the first two-fifths are conventionally credited to the jejunum and the remaining three-fifths to the ileum. It is a cylindrical tube continually decreasing in size. The diameters are variously stated, Testut giving the mean diameter of the upper part as from 25–30 mm. and that of the lower as from 20–25 mm. These latter figures our own measurements confirm, since on thirty-seven inflated specimens of the lower end the average diameter was 24 mm., the extremes being 17 and 37 mm. Chaput and Lenoble[2] assert that the inferior circumference is reduced internally to 32 mm. (on inflated specimens to 50 mm.) by a valve near the cæcum. This valve, which we have found in about one-third of the cases, is remarkable in being always situated on the posterior aspect of the gut, generally at a sharp bend; it often contains a small artery, and is probably formed by the folding in of the muscular coat. Its position is frequently near the point at which the ileum begins to lie against the wall of the cæcum, but it may be 2.5 cm. or more higher. The valve is sometimes double, and varies in height from 2 mm. to 1 cm. We have not found, however, that this fold is necessarily the narrowest point of this part of the gut. A piece of the intestine from the upper part of the jejunum weighs more than one of equal area from the lower part of the ileum, owing to the greater thickness of the walls of the former and to the greater development of the valves in that part. The structure of this part of the small intestine has already been described (page 1634).

[1] Arch. für Anat. und Entwicklng., 1887.
[2] Bull. Soc. Anat. de Paris, 1894.

The Mesentery and Topography of the Jejuno-Ileum.—Since consideration of the mesentery is indispensable for the study of the disposition of the folds and relations of the small intestine, this structure next claims attention. The serous covering of the gut itself requires no further description than to note that it completely surrounds the bowel, except at the double line of its attachment, where there is left space just large enough for the passage of the vessels and nerves. The attached border of the mesentery (Fig. 1399) extends from the left of the front of the first

FIG. 1403.



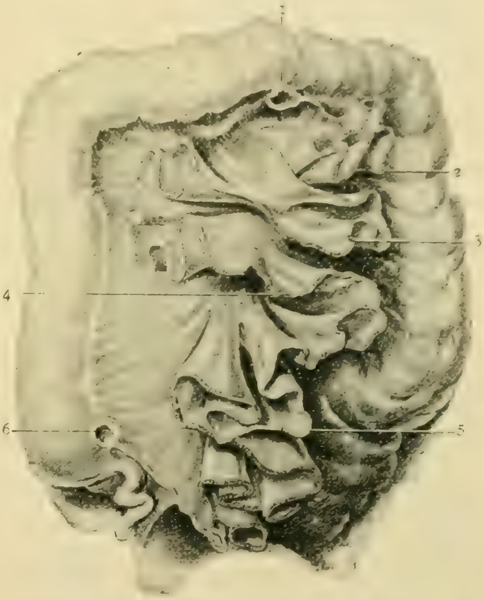
Formalin subject; liver, stomach, transverse mesocolon, and colon have been removed, leaving other abdominal organs *in situ*; attachment of cut peritoneum indicated by white line.

or second lumbar vertebra, immediately below the end of the duodenum, where the superior mesenteric artery enters it, to the right sacro-iliac joint, a distance of about 15 cm. (6 in.). The relations of the upper part of the fold are determined by the shape and position of the duodenum. Probably the usual course of the mesenteric attachment is from the front of the aorta downward on the fourth part of the duodenum, across the vena cava to the right sacro-iliac joint. With a V-shaped duo-

denum the line of the mesentery is usually on the right of the gut; with a duodenum that crosses the aorta the line is across the third part. The lower end of the mesentery is determined by the degree of adhesion of the right mesocolon to the abdominal wall. It rarely stops short of the sacro-iliac joint, but it may be continued farther into the right iliac fossa.

The free or intestinal border of the mesentery is some 6 m. or about 20 ft. long. In the middle the distance between the borders is from 20–22.5 cm. (8–9 in.). Near its origin, in the first six inches of the intestine, the mesentery has reached a breadth of from 12–15 cm. (5–6 in.). At the lower end its breadth is more uncertain, being usually slight, only from 2.5–5 cm. for the last six inches. It increases with age, presumably concurrently with the increase of girth. The mesentery contains vessels and nerves as well as lymphatic nodes between its folds; these structures may lie in a considerable mass of fat, adding to the thickness, which is much greater, on account of the size and number of the vessels, in the upper part than in the lower. The larger lymph-nodes and the fat accumulate chiefly near the spinal border, where the mesentery may be very thick and heavy, while the part near the intestine, except in the case of excessive fatty accumulation, is always thin and yielding. It is evident that the mesentery with an attached border of only 15 cm. (6 in.) and a free one of 6 m. (20 ft.) must be very much folded; and further, that while the intestinal border must present a vast number of totally irregular and transitory folds, changing with the movements of the gut, the heavier and more fixed part of the mesentery near the root must present certain chief folds the position of which is tolerably stable.

FIG. 1404.



Typical disposition of folds of mesentery shown after removal of jejuno-ileum. 1, end of duodenum; 2, 3, 4, jejunum; 5, ileum; 6, termination of ileum into large intestine. (*Mall.*)

Henke[1] has shown that if the hand be introduced among the coils of intestines in the line of the left psoas muscle and carried upward, it enters the concavity of a horseshoe-shaped fold of the mesentery, and that the intestines easily fall apart to either side. The coils on the left are in the main transverse and those to the right chiefly vertical. This plan, although sometimes obscure, is often beautifully clear, especially in infants. Weinberg,[2] from studies on the new-born infant, has carried the plan into further details. He finds that the upper two-fifths of the intestine are arranged in transverse folds in the upper left part of the abdomen; the middle fifth lies in the left iliac region without definite arrangement; the last two-fifths are in the median part and in the right iliac region, disposed in the main vertically. Still, cases occur at all ages in which the plan is obscure. Mall[3] has traced the plan of the intestines throughout development, and incidentally confirms Weinberg's statements. The following account of the normal arrangement in the adult is essentially according to his researches. The gut is to be conceived as arranged in spiral coils travelling from the left hypochondriac region to the right iliac fossa, successive coils being in the main parallel. Starting from the duodenum, there are two transverse folds in the left hypochondrium, followed by a long fold that goes across the body and back. Some less distinctly transverse folds occupy the left iliac fossa. The

[1] Arch. für Anat. und Entwicklng., 1891.
[2] Internat. Monatsschrift für Anat. und Phys., Bd. xiii., 1896.
[3] Arch. für Anat. und Entwicklng., 1897. Supplement Bd.

remainder is disposed vertically, occupying the lower part of the umbilical region and the pelvis, and extending on the right as far as the large intestine will allow. The vertical arrangement of this portion is generally less striking than the transverse disposition of the preceding. The end of the ileum rises from the pelvis into the right iliac fossa. There are, of course, frequent deviations from the above plan of arrangement of the folds. It is easy to see that the appearance at the surface of some that are usually deep would obscure the plan. It is worth noting that adjacent folds should never be assumed to be continuous.

Blood-Vessels.—The *arteries* of the jejuno-ileum are branches of the superior mesenteric, which enters the mesentery below the pancreas. The vessels for the gut are straight ones arising from the arterial arches. In the upper part they are from 4–5 cm. long, 3 cm. in the middle, and very small at the end of the ileum. They run without anastomoses to the edge of the gut, where they break up into bunches of slightly diverging branches. All of these usually go to one side of the gut, each alternate vessel taking a different side, although sometimes a vessel may send branches to both sides. Anastomoses in the walls of the gut between the branches of neighboring arteries are not numerous, and occur only between very fine vessels, except opposite the mesentery, where vessels of the different sides meet. The distribution of the veins is essentially the same.

The **lymphatics,** large and numerous, empty into the mesenteric nodes, which they connect. These lymph-nodes vary in number from one to two hundred, the largest lying near the root of the mesentery, from which position they grow smaller as they approach the free edge. There are no nodes, however, between the gut and the last vascular arch, unless, perhaps, near the very end of the small intestine.

The **nerves** of the entire small intestine are from the solar plexus. They receive many cerebro-spinal fibres through the splanchnics.

Meckel's Diverticulum.—This is a protrusion from the ileum, shaped like the finger of a glove, and found in some 2 per cent. It is the remnant of the vitelline duct, which at an early stage connects the gut with the yolk-sac. It springs most frequently from the free border of the bowel, sometimes, however, from the side, and, as a rule, but not invariably, is composed of all the intestinal coats. Its usual position is within 1 m. (on an average, 82 cm.) of the cæcum. The diameter of the diverticulum is usually that of the gut, but it may be less and associated with a conical form. The length varies from 2.5 cm. or less to 17.5 cm. (7 in.), although ordinarily between 2.5 and 7.5 cm. (1 and 3 in.). As a rule, its end is free, but often a delicate band extends from its apex to the umbilicus or to some of the contents of the abdomen, generally the mesentery.[1] The occasional diverticula, found especially in the duodenum, are probably pathological and do not include the muscular coat.

PRACTICAL CONSIDERATIONS: THE SMALL INTESTINE.

1. *The Peritoneal Coat.*—This is complete below the duodenum except at the mesenteric aspect, where the two layers of peritoneum diverge for about 8 mm. (⅓ in.). The jejuno-ileum is therefore practically an intraperitoneal, and not merely an intra-abdominal, viscus, although, of course, really outside the peritoneal sac. Inflammation of this portion of the general peritoneum is more apt to be acute, to spread rapidly, and to be attended by serious or fatal results than is that of any other portion. Such infection is frequent on account of the great length of the small intestine, its exposure to trauma, the thinness of its muscular walls, the variety and number of the lesions of its mucosa, its close relation to all the intra-abdominal viscera, and its consequent participation in their injuries and diseases. Direct transmission of infection from within outward is favored by the relatively intimate relation between the peritoneal and muscular coats, the subserous areolar tissue being much scantier and containing much less fat than that intervening between the parietal peritoneum and the fasciæ and muscles of the abdominal wall. The extent and fatality of peritoneal inflammation result from the facility with which it spreads by both continuity and contiguity, and from the fact that, *cæteris paribus*, its toxic products are proportionate in amount to the area involved. The association of the spinal and sympathetic nerves in the

[1] Lamb: American Journal of the Medical Sciences, 1893.

intramuscular *plexus of Auerbach* and the submucous *plexus of Meissner*, and their connection with the lower seven intercostal nerves distributed to the skin and muscles of the abdomen, explain (*a*) the abdominal rigidity and tenderness which often precede an extension of disease from the visceral to the parietal peritoneum; (*b*) the paresis or paralysis of the intestines which is so common as a symptom of peritonitis, and which favors stasis of intestinal contents, putrefaction, and distention; (*c*) the vasomotor disturbance which is an important, if not the chief, factor in the production of meteorism; (*d*) the vomiting, first reflex and then from irregular muscular contraction (reversed peristalsis); and (*e*) the reference of the early pains, no matter what the seat of the peritonitis, to the epigastrium or umbilicus,—*i.e.*, to the solar and superior mesenteric plexuses.

The usual cause of peritonitis of the small intestine, by infection from within, is penetration of its walls by the colon bacillus, following epithelial necrosis or ulceration due to catarrh or to various forms of infection, or secondary to diseases which produce engorgement of the terminal vessels of the portal system. It is sometimes, in a less acute form, a final phenomenon in fatal cases of renal or cardiac disease. It may follow tuberculosis or typhoid ulceration of the solitary or agminated lymph-nodules.

In all cases of enterorrhaphy—as after resection or anastomosis—especial attention should be paid to the non-peritoneal area included between the two mesenteric layers. The success of these operations depends primarily upon the rapid union of apposed peritoneal surfaces; hence the serous coat, including the two layers of the mesentery, should be brought together through the complete circumference of the bowel and accurately sutured.

2. *The Muscular Coat.*—Irregular or spasmodic contraction of the muscular wall of the small intestine produces typical "colic," the pain being analogous to that felt in a "cramp" of one of the voluntary muscles. Intestinal colic is not associated with tenderness of the surface of the abdomen, or with rigidity of the abdominal muscles, and is usually relieved by firm pressure,—supporting and controlling the affected segment of gut. The abdominal wall may be moved freely over the underlying viscera. It may thus be distinguished from the early pain of peritonitis.

The greater thickness of the inner—circular—coat causes longitudinal wounds to gape more than transverse ones. The latter are more apt to gape if they are at the free border of the gut, where the longitudinal fibres are most numerous. As the muscular coat in its entirety lessens in thickness from above downward, wounds of the jejunum gape more than those of the ileum. Intestinal punctures usually, and very small wounds not infrequently, are closed by muscular action, so that healing takes place without extravasation of intestinal contents. Slightly larger wounds may be stopped by a plug of mucous membrane. This is favored in the upper portion of the tube by the presence of the valvulæ conniventes and in the lower part by the laxity of the submucosa. This eversion of the mucous membrane, caused by muscular contraction, must always be overcome in the suture of intestinal wounds, since the mucous surfaces will not unite with each other.

3. The *mucous* and *submucous coats* and their contained glandular and vascular structures are subject to many varieties of disease. If *catarrhal inflammation* affects the mucosa of the small intestine, it is apt, if localized in the duodenum, to be associated with gastritis and to extend into the bile-ducts, causing jaundice. If in the jejuno-ileum, it may be mistaken for colitis; usually, if in the small intestine, the diarrhœa is less marked, the colicky pains are greater, borborygmi are fewer, less mucus is found in the stools, and tenesmus is absent. Neither duodenitis, jejunitis, nor ileitis can, however, positively be diagnosticated from one another or from general intestinal catarrh (Osler).

Ulcers of the duodenum are in the vast majority of cases (242 out of 262, Collin, quoted by Weir) situated within 5 cm. (2 in.) of the pylorus (the most movable portion of the duodenum) and are most often on the anterior wall, especially its right side. The peritoneum of the right side of the first part of the duodenum looks into the general peritoneal cavity, and of the left side into the lesser cavity (page 1647). When perforation follows, the general peritoneal cavity is therefore likely to be infected, and the death of one-half of the subjects of perforating duodenal ulcer from general peritonitis is thus accounted for. The second part of the duodenum is

in close relation on the lower part of the right aspect with the liver and gall-bladder on the upper part of the left aspect with the head of the pancreas and foramen of Winslow, and posteriorly is partly uncovered by peritoneum and rests on areolar tissue and the common bile-duct.

The general relations of the duodenum (page 1645) explain the remaining lesions following duodenal ulcer,—*e.g.*, perforations into the gall-bladder, liver, or colon ; opening of the hepatic artery or the aorta, or of the superior mesenteric or portal vein ; or the development of subphrenic abscess.

As compared with the symptoms of gastric ulcer, *pain* is apt to be less on account of the relative immobility of the duodenum ; *vomiting* after feeding is later ; *hemorrhage* is often greater on account of the larger vessels that may be involved ; *bloody stools* are more common, as is *jaundice* from the involvement of the bile-duct.

In exposure of this part of the duodenum it is well to remember the suggestions of Pagenstecher (quoted by Weir),—viz., that the fundus of the gall-bladder when distended lies in front of the duodenum ; that by raising and drawing forward the transverse colon, which lies in front of and below the horizontal portion of the duodenum, the first portion is revealed ; and that by pushing the stomach and pylorus to the left and elevating the liver, access to the region of perforation may be gained. In emaciated patients with contracted stomachs the duodenum may be found lying above the level of the transverse colon.

Infection through the mucous coat has already been spoken of. If of the *tuberculous* variety, it affects chiefly the lower part of the ileum, and tends, as is characteristic of that disease, to follow the course of the vessels which run from their entrance at the mesenteric attachment transversely around the gut. If such ulcers cicatrize, they are therefore especially prone to lead to stricture of the intestine, a very rare sequel of typhoid ulceration, which, affecting the same portion of the small intestine, extends in the line of the agminated lymph-nodules,—*i.e.*, longitudinally. The tuberculous ulcer sometimes produces a slow general peritonitis, rarely a localized abscess, much more rarely an acute perforation with general septic peritonitis, as the process is so slow that protective adhesions to neighboring coils of gut or to the parietal peritoneum have time to form.

Typhoid ulcers cause perforation in 6.58 per cent. (Fitz) of all cases. The large majority of perforations occur in the ileum, most of them within 60 cm. (2 ft.) of the ileo-cæcal junction. In operation this should therefore be sought for and the ileum followed upward from that point. The ulceration may so thin the intestinal wall as to permit of leakage and the production of general peritonitis without actual perforation ; or it may be accompanied by such an extensive exudate as to make the ileum palpable, a condition which, in conjunction with localized tenderness and abdominal rigidity (*vide supra*), has led to many mistaken diagnoses of appendicitis in cases of typhoid fever.

Syphilitic ulceration of the small intestine is rare, but is said to be most frequent in the upper portions (Rieder).

The lymphatics of the mucous and submucous coats empty into the mesenteric lymph-nodules (page 1643) and convey to them various forms of infection or disease, —typhoid, carcinomatous, tuberculous, etc.

The veins emptying into the vena porta through the superior mesenteric are likewise channels of infection, ulceration of the bowel sometimes resulting in abscess of the liver.

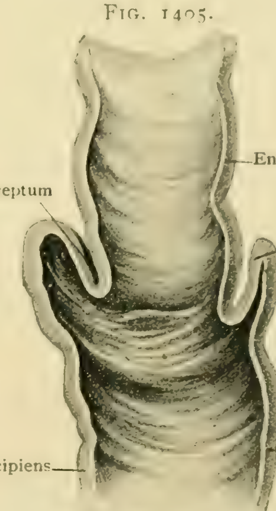
Contusion and *rupture* of the small intestine are favored by its exposure to trauma through its close apposition to the abdominal wall, which, if relaxed, offers but little protection. The interposition of the greater omentum with its contained fat is a slight safeguard, but the movement of the coils of gut upon one another and their elasticity are of much more value.

Contusion here, as elsewhere, may be followed later by infection and ulceration. Traumatic rupture is much more frequent in the jejunum and ileum than in any other portions of the alimentary canal (of 219 cases, 79 per cent. were in the small intestine, 11.5 per cent. in the colon, and 9.5 per cent. in the stomach, Petry). The duodenum suffers very infrequently on account of its sheltered position ; other-

wise its lower portion—the most fixed part of the intestine—would probably be more often injured. The upper portion of the jejunum, which partakes somewhat of this fixity, is more commonly ruptured than any other part. So, too, the most fixed part of the ileum—that nearest the ileo-cæcal junction—is most often the site of rupture. An incarcerated or irreducible hernia may constitute a fixed point of the gut and favor its rupture elsewhere from trauma to the surface of the abdomen.

Ruptures of the intestine, like wounds or obstruction, are more serious the higher they are situated. The nervous disturbance and shock are greater, possibly on account of the more immediate relation of the lesion and of the resulting pathological changes to the great nerve-plexuses or to the pericardial portion of the diaphragm (Crile); vomiting begins earlier and is more severe for the same reason; peristalsis is more vigorous (as the muscular coat of the gut is better developed) and therefore rapid extravasation of intestinal contents is more likely and spontaneous closure of a wound less likely to occur; and, if the condition is at all chronic, nutrition is interfered with to a greater extent. Clinical experience shows that in such injuries the anatomical are more potent than the purely bacteriological factors, which would tend to make jejunal wounds *less* dangerous than those lower in the tract. Investigation has shown (Cushing and Livingood, and later Lorrain Smith and Tennant) that the bacterial flora in the upper portion of the intestinal tract is more scanty than in the lower portion; and it is true that peritonitis following intestinal wounds, operative or accidental, is dependent for its characteristics upon the bacteria at the site of lesion, and that the prognosis should be favorable in proportion to the scarcity and innocuousness of the micro-organisms present. But the anatomical conditions, by adding to shock, favoring intestinal extravasation, and minimizing the chance of a reparative peritonitis, are more than sufficient to counterbalance the relative dearth of bacteria.

FIG. 1405.



Longitudinal section of intussuscepted gut, showing layers.

It should be remembered that the position of the wound or contusion on the surface of the abdomen is of but slight value in determining the area of gut involved. Thus, a jejunal fistula following a wound was situated midway between the umbilicus and pubes, but measurements made by attaching ligature silk to portions of food swallowed and extruded at the fistula showed that the latter was but 119 cm. (3 ft. 11 in.) from the incisor teeth, and was therefore high in the jejunum (Cushing.)

It may be noted that fistulæ so situated are apt to be complicated by excessive dermatitis, supposed to be due to the presence of pancreatic juice in the discharge, as gastric, biliary, and colonic fistulæ do not give rise to this trouble in any such degree of severity.

Obstruction of the small intestine may be due to (*a*) *foreign bodies* (including intestinal concretions and gall-stones that have ulcerated into the duodenum), and is then most apt to occur at the ileo-cæcal junction on account of the narrowing of the canal at that point; (*b*) *bands*, producing constriction of a coil or knuckle of gut, such bands arising from the elongation of adhesions due to previous peritonitis, from inflammatory attachment of the free end of Meckel's diverticulum (page 1652), of adventitious diverticula (from protrusion of the mucous membrane through the muscular coat), or of the appendix. Either the Fallopian tubes, the appendices epiploicæ, the omentum, or the mesentery may in like manner become converted into constricting bands; (*c*) *stricture*, as from tuberculous ulcer in the ileum or syphilitic ulcer in the jejunum; (*d*) *volvulus*, especially in the lower part of the

ileum when its mesentery has been elongated by prolonged stretching, as in the presence of an old hernia (Maylard); (*e*) *internal herniæ*, as into the duodeno-jejunal, pericæcal, or intersigmoid fossæ, or through the foramen of Winslow, or through an aperture in the omentum (page 1758), which may be traumatic or may be one of the rounded openings due to congenital atrophy of a comparatively avascular area of the mesentery of the terminal portion of the ileum and embraced within the ileo-colic artery and the lowest vasæ intestini tenuis; (*f*) *herniæ* through the usual hernial apertures or regions of the parietes (page 1762); (*g*) *intussusception*, one form of which is due to irregular contraction of the circular fibres of the muscular coat, so that as the peristaltic wave passes downward a segment of gut, made smaller by this contraction, is forced into the portion immediately beneath it, which is of larger calibre as a result of having failed to contract at the proper time; (*h*) *pressure from without*, as from tumors, which, as they must meet with counter-resistance and relative fixity of the gut to produce constriction, most often affect the duodenal (as in cancer of the pancreas), upper jejunal, or ileo-cæcal segments; (*i*) *peritonitis*, the relation of which to intestinal obstruction will be subsequently explained (page 1756); (*j*) *tumors* of the intestines themselves, not very frequent in the small intestine, but most often found at its two extremities.

The *position* of the different portions of the small intestine varies greatly. The lower end of the duodenum, the upper end of the jejunum, and the lower end of the ileum are the most fixed points. A description of the normal arrangement of the coils of the jejuno-ileum has been given (page 1651).

Of the duodenum only the first portion has been found involved in internal herniæ. The more or less vertical coils of the jejunum, and especially those of the terminal portion of the ileum which occupy the pelvis when the bladder, rectum, and sigmoid are not distended, are those most likely, for *a priori* reasons, to be found in inguinal or femoral enteroceles, but clinical evidence in support of this is not conclusive. In umbilical hernia the jejunum is apt to be involved, and the gravity of this form of hernia, when strangulated, is supposed to be partly due to this fact as well as to the effect upon the circulation of the constricted coil produced by the sharp edge of the cicatricial tissue which surrounds the opening and aggravated by the downward pull, through gravity, of the remainder of the intestines.

When the stomach is full the intestines are depressed; when it is empty they rise, so that in the left hypochondriac region they may be in contact with the diaphragm. If the colon is distended, the small intestine can occupy but little of the lumbar, epigastric, or hypochondriac regions. Conversely, if the small intestine is distended, it may so fill the pelvis and compress the rectum as to prevent the passage of a tube or bougie into the sigmoid, and thus give rise to a mistaken diagnosis of obstruction at that point. If the spleen is enlarged, they are carried downward and to the right; if the liver, downward and to the left; if the bladder or uterus, upward.

In ascites they are above the fluid,—*i.e.*, in the umbilical region in the supine and the epigastric region in the erect position.

Normally the coils of the small intestine are closely applied to one another, and this condition, by permitting of rapid adhesion, and thus of isolation of an infected focus, has saved thousands of lives, especially in cases of appendicitis and pyosalpinx, and less frequently in cholecystitis and other forms of intra-abdominal infection.

Operations.—The principles which should govern in opening the small intestine, in avoiding or controlling hemorrhage, and in suturing wounds accidental or operative have been sufficiently explained (page 1653).

The recognition of the duodenum is not difficult. It occupies portions of the right hypochondriac, right lumbar, and umbilical regions. The spine of the second lumbar vertebra is just above it. The hepatic flexure of the colon is anterior to it at a point just below the ninth rib on the right side. The mesentery commences at the duodeno-jejunal junction. A notch which can be felt in the peritoneum serves as a guide to this particular part (Maylard).

Duodenotomy may be required, either as an aid or as the main avenue of approach, in cases of impacted calculus in the common bile-duct (page 1732). It is

rarely needed for the removal of foreign bodies, as those small enough to pass the pylorus effect, as a rule, only temporary lodgment in the duodenum and usually reach the ileo-cæcal region.

The jejunum may be distinguished from the ileum by its greater width and thickness, its deeper color, and by the presence of the many large folds of the valvulæ conniventes which can be seen in the collapsed and tense gut by transmitted light. By drawing a loop of intestine out of the abdomen so that, with the loop parallel with the long axis of the body, its mesentery is stretched and straightened, it is easy to determine which is the upper end of the loop, and so to follow the gut either towards the duodenum or the cæcum, as may be desired. The finger should be passed down to the spine, keeping in close contact with the mesentery; if it remains on one side until the posterior attachment is reached, it is evident that there is no twist of the loop and that its upper portion is normally the portion nearest the stomach. As loop after loop is examined, if the intestine leads in an upward direction the color becomes paler, and the walls become thicker owing to the valvulæ conniventes and to the increase in the submucous and muscular coats.

Other methods of locating with accuracy a given coil of bowel are (1) by means of the length of the vasa recta (3–5 cm. in the upper and 1 cm. or less in the lower portion); (2) by the vascular loops from which the vasa recta originate, which are primary in the first four feet of the mesentery. Secondary loops appear as we go farther down, until in the lower third there is a net-work of loops; (3) by the loops or "lunettes" at the intestinal attachment of the mesentery, best visible by transmitted light. Below the first eight feet these lunettes disappear (Monks).

Enterotomy—for temporary relief of obstruction or distention or for the removal of a foreign body—is done at as low a point as circumstances permit, through a transverse incision at the part opposite the mesenteric attachment.

Enterostomy—the establishment of a permanent fistula for the purpose, if it is a *jejunostomy*, of feeding the patient in cases of obstruction of the alimentary tract above the opening; or if it is an *ileostomy*, of relieving fecal accumulation in cases of obstruction at a lower point—is done by suturing the selected knuckle of gut to the parietal peritoneum by a double line of sutures and opening the bowel between them.

Enterectomy and *entero-anastomosis* (either lateral or end-to-end) require for their performance, so far as anatomy goes, application of the facts and principles to which reference has already been made.

THE LARGE INTESTINE.

The general plan of the large intestine has already been given (page 1617). It is easily distinguished from the small intestine, not so much by its greater size as by being sacculated, excepting, perhaps, the sigmoid flexure.

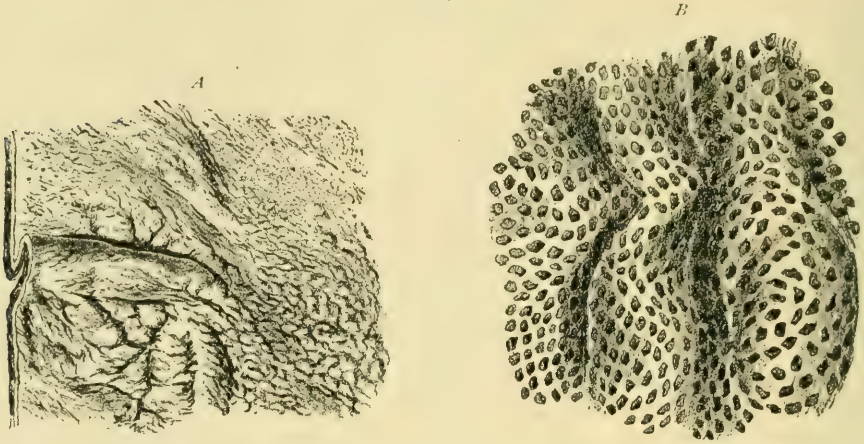
The length of the large intestine from the root of the appendix to the beginning of the rectum is, according to Treves, about 1.4 m. (4 ft. 8 in.) in man and 5 cm. (2 in.) less in woman. The extremes were 2 m. (6 ft. 6 in.) and 1 m. (3 ft. 3 in.). Excluding the dilated part of the rectum, the capacity decreases from above. Owing both to variation and to occasional cases of extreme contraction as well as of distention, the diameter is very uncertain. It may vary from 7 cm. ($2\frac{1}{3}$ in.) to 3.5 cm. ($1\frac{2}{3}$ in.) without the more extreme figures implying a pathological condition.

Structure.—The **mucous coat** of the large intestine agrees in its essential structure with that of the small gut, consisting of a stroma resembling adenoid tissue, covered by a single layer of columnar epithelium exhibiting a cuticular border. The chief difference, on the other hand, is the absence of villi, in consequence of which the velvety appearance imparted by the latter is not seen in the large intestine. Valvulæ conniventes are also wanting, although there are projections into the large gut involving all or a part of the coats internal to the serous tunic. The muscularis mucosæ is less regular in its development, being feebly represented in the colon and exceptionally thick in the rectum.

The *glands of Lieberkühn* in general resemble those of the small intestine, but are larger (about .45 mm. in length), and form a more regular and less inter-

rupted layer of parallel tubules. The largest ones are in the rectum, where they measure .7 mm. (Verson). The lining of the glands is conspicuous on account of the great number of goblet-cells, which in the middle and upper parts of the tubules

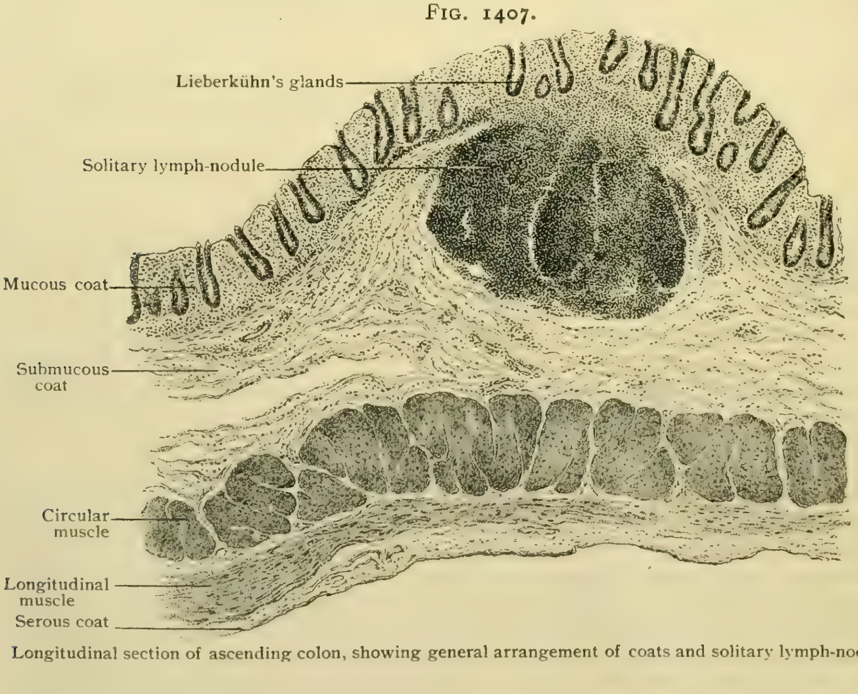
FIG. 1406.



Surface views of mucous membrane of ascending colon. *A*, natural size; *B*, magnified 30 diameters, showing orifices of Lieberkühn's glands.

often exist in such profusion that the ordinary cells are almost entirely replaced; towards the deepest part, or fundus, of the glands they are comparatively infrequent. The presence of goblet-cells in such numbers accounts for the considerable amount of mucus normally poured into the large intestine.

FIG. 1407.



Longitudinal section of ascending colon, showing general arrangement of coats and solitary lymph-nodule. × 30.

The *lymphatic tissue* in definite collections occurs as solitary nodules only, Peyer's patches being absent within the large intestine. The lymph-nodules, which occupy a portion of the submucous coat as well as the mucosa, are largest and most

numerous in the cæcum, and especially in the vermiform appendix, in which the nodules are so plentiful that they form in places almost a continuous mass of lymphoid tissue. The solitary follicles are less frequent in the colon, but are again numerous in the rectum. They are generally of larger size than in the small intestine, measuring from 1.5–3 mm. in diameter, and are situated at the bottom of pit-like depressions on the mucous surface into which the nodules project.

The **submucous coat** closely corresponds with the similar areolar tunic of the small intestine, allowing of fairly free

FIG. 1408.

Portion of mucosa of large intestine, showing Lieberkühn's glands cut lengthwise; many epithelial elements contain mucus and are "goblet-cells." × 225.

FIG. 1409.

Mucosa of large intestine sectioned parallel to free surface, showing Lieberkühn's glands cut crosswise; glands separated by intervening stroma of mucous membrane. × 225.

FIG. 1410.

Portion of descending colon, somewhat distended, showing sacculations, tænia, and epiploic appendages.

FIG. 1411.

Longitudinal section of epiploic appendage. × 23.

play of the mucosa. In addition to the blood-vessels, lymphatics, and nerve-plexus of Meissner, it contains the deeper and more expanded parts of the solitary nodules.

The **muscular coat** consists of a thicker layer of internal circular fibres and of an external longitudinal one, the fibres of which are in most places collected into three bands. Although longitudinal fibres exist between these, they are few and apparently not quite universal. Beginning in the cæcum, at the base of the vermiform appendix, the three bands, or *tæniæ coli*, continue along the large intestine as far as the sigmoid flexure, over which and the rectum the bands are only two, and no longer sharply defined. In the rectum one is on the front and the other—the stronger—behind. The circular fibres increase very much towards the end of the rectum, the muscular apparatus of which will receive special description (page 1675).

FIG. 1412.

Transverse section of injected large intestine, showing distribution of arteries to coats. × 30.

The **serous coat** which once surrounded the gut, in certain places disappears during development, and in others its arrangement becomes modified by new relations with other peritoneal layers. These features will be described with the parts concerned. In structure it corresponds with the serous coat of other parts of the intestinal tube.

The **appendices epiploicæ** are little fringes or bags of peritoneum containing fat hanging from the large intestine. They may be as much as 2.5 cm. (1 in.) in length, and are very prominent in fat subjects, but in thin ones may be overlooked. They are found particularly on the inner aspects of the ascending and descending colon and on the lower one of the transverse colon. It is often stated that they occur along one of the bands, but this relation is at least not constant, although they are generally arranged in a single line. They are found also on the sigmoid flexure. It is usually stated that they are not present during childhood. Oddono,[1] however, has shown that they appear in the fifth month of fœtal life, first on the descending colon and sigmoid flexure. We have seen them before birth.

The **blood-vessels, lymphatics,** and **nerves** of the large gut in general follow the arrangement already described in connection with the small intestine (page 1642).

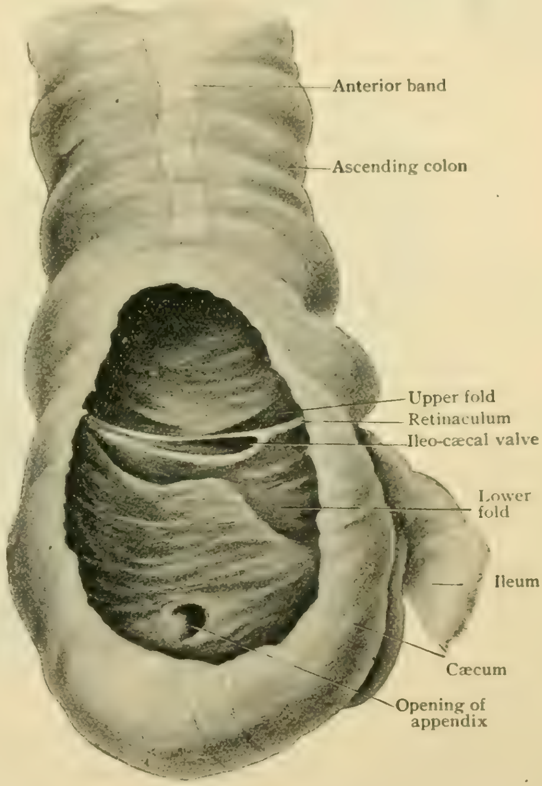
THE CÆCUM.

The cæcum, or blind gut, the first part of the large intestine, is a pouch hanging downward at the junction of the ileum and colon, from which the vermiform appendix arises. The ileum opens into the large intestine by a transverse orifice placed in-

[1] Dal Bollettino della Societa Medico-Chirurgica di Pavia, 1889.

ternally and somewhat posteriorly. From the top of the ileum a deep furrow passes posteriorly partly around the gut, and a less marked one is found in front. Although starting as just stated, the furrows at once descend a little, so as to represent truly the middle of the orifice. These serve as an external boundary between the cæcum and the colon, which are much alike in general characters. The average length of the cæcum in the adult is between 6 and 7 cm. (about 2½ in.), and its breadth about 8 cm. (3⅛ in.).[1] The bands of the colon are continued onto the cæcum of the adult, and terminate at the origin of the appendix. One band is in front and the other two externally and internally at the back. The parts between the bands are generally expanded pouches, which may be subdivided by horizontal constrictions. There are two chief forms of cæcum with several minor modifications: the first is a persistence of the fœtal type, in which the cæcum has the shape of a cornucopia bent towards the left, with the tapering end continued as the vermiform appendix; the other, which is the usual, and occurs in from 91–94 per cent. of adults, is due to the part between the external and the anterior band growing out of all proportion, so that the pouch between them becomes the lowest part, apparently the apex, the appendix arising from the internal posterior side near the ileum. In extreme cases the two may be very close together. Very rarely the cæcum is symmetrically sacculated, with the appendix at the lower end.

FIG. 1413.



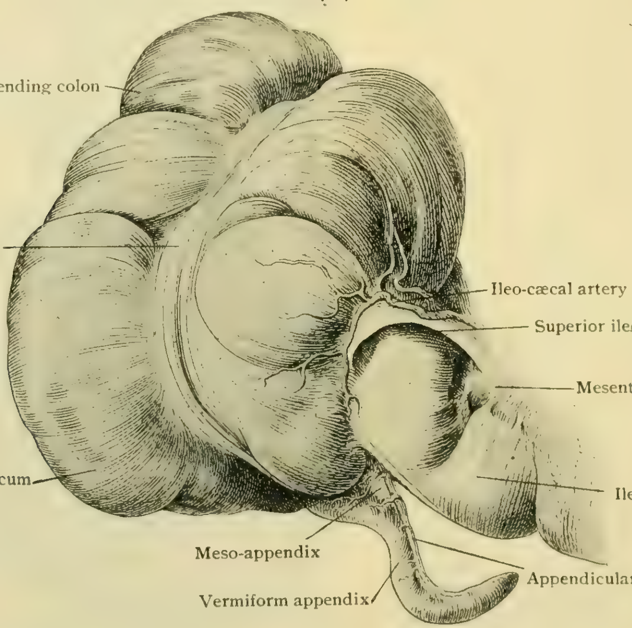
Beginning of large intestine, somewhat inflated; part of anterior wall removed to show ileo-cæcal valve and orifice of vermiform appendix.

To understand the **interior of the cæcum** it must be remembered that the end of the ileum is thrust in at the angle between the colon and cæcum in such a way that originally in fœtal life all the coats were involved. The serous coat is replaced by areolar tissue where two layers come together and new longitudinal muscular fibres are subsequently developed which do not enter the folds; however, the original longitudinal muscular layer, as well as the circular one, does so. The latter is thickened inside the fold. The ileum, as it approaches its end, lies between the surface of the cæcum below and the lower swelling of the colon above; thus the upper of the two lips of the elliptical opening is composed of colon and ileum, the lower of ileum and cæcum. They form prominent shelf-like projections into the large gut, opposite the external furrows, and constitute the **ileo-cæcal valve** (**valvula coli**). The folds meet at the ends of the opening, forming single continuations or *retinacula*, of which the posterior is much the larger. It often extends across the posterior to the lateral aspect of the gut. The two segments converge, but at different angles. The upper, slanting somewhat downward, is approximately horizontal, while the lower is more nearly vertical. The orifice of the ileum between these folds is elongated when the gut is distended, the posterior end being sharper than the anterior. The diameter of the segments, measured from the origin to the free edge on 35 inflated and dried

[1] Berry: The Anatomy of the Cæcum, Anat. Anzeiger, Bd. x., 1895.

specimens, is as follows: average of upper segment 25 mm., of lower 33 mm. The largest pair was an upper of 37 mm. and a lower of 44 mm.; the smallest of 12 mm. and 3 mm. respectively. The last, perhaps, was pathological; the next smallest was 14 mm. and 19 mm. We have seen a cæcum with the upper segment entirely wanting. The absence of both has been observed. The average length of the ileo-cæcal opening on 30 similar specimens was 31 mm., the extremes being 46 mm. and 21 mm. It is probable that, owing to the shrinking of the tissues, these dimensions of the opening are excessive. Although the lower fold is the larger, the upper overlaps it almost invariably, so that when the valve is closed the two edges do not come in contact, the orifice being closed by the application of the lower fold to the under surface of the upper one. Inflated specimens show that the upper fold is tense, while the lower remains flaccid. Much difference of opinion exists as to the completeness of the closure of the ileo-cæcal valve, and experiments do not agree. If the experiment of injecting water or air from the colon be performed *in situ*, the closure is more likely to be perfect than if the parts have been removed. These experiments, however, do not represent the true con-

FIG. 1414.



Cæcum and related structures seen from the left.

ditions during life, since the tonicity of the muscular fibres of the gut is lost, and, in the opened abdomen, the pressure of the viscera on the end of the ileum is less than normal. In life the valve probably is efficient.

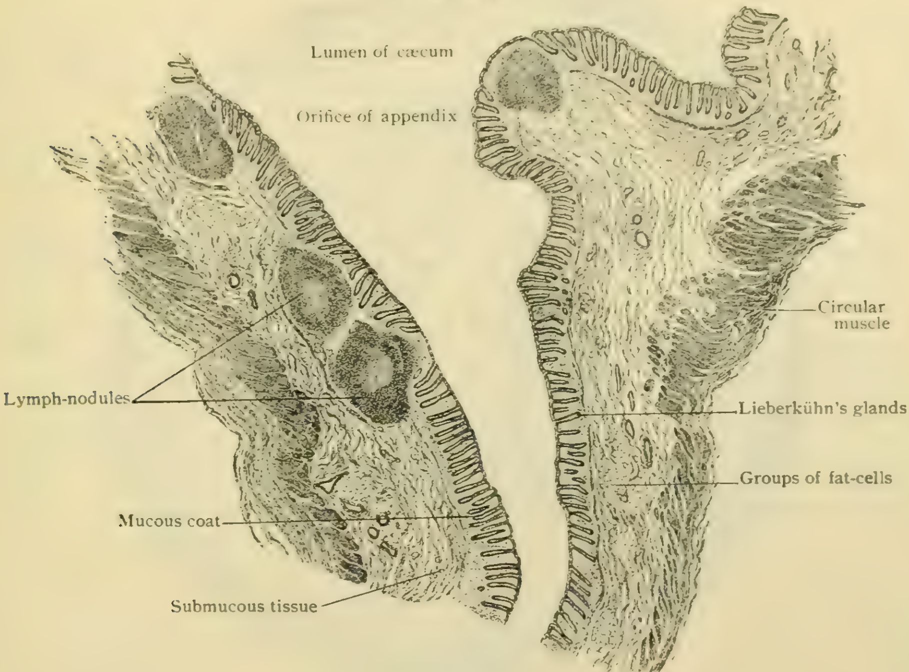
The **orifice of the vermiform appendix** is very variable. In some cases the cæcum narrows to it so gradually that it is hard to say where it begins; in others it begins suddenly with an oval or round opening measuring from 5 mm. or less to 1 cm. or more. The *valve* which often is found at the orifice is not usually a true valve, but the projection made by the wall at the union of cæcum and appendix in the entering angle when it arises obliquely. According to Struthers, there is no valve when it arises at right angles. Owing to its usual upward course, the fold is most often on that side when present. We have seen a true valve as a small independent fold; usually, however, there is no effective guard to the entrance of the appendix.

Position.—The cæcum is situated in the right iliac fossa, resting on the iliac fascia covering the ilio-psoas muscle, above the outer part of Poupart's ligament,

about half below and half above the level of the anterior superior iliac spine. Sometimes, owing to the shortness of the ascending colon, the cæcum remains in the fœtal position under the liver, or it may be arrested at any part of its descent. It not rarely hangs down into the pelvis, and when the lower part of the mesentery is long, particularly if the lower part of the ascending colon be not attached to the posterior wall, it may be very freely movable. In cases of *mesenterium commune* there seems to be no anatomical reason why it should not be anywhere. The cæcum is sometimes turned up over the lower part of the ascending colon, but we cannot agree with Curschmann's[1] statement that this is not rare. In these cases the appendix rises from near the highest point of the cæcum. We have seen the cæcum in the umbilical region with two vertical coils of small intestine occupying the right flank.

Structure.—The description of the structure of the large intestine already given (page 1657) applies in general to the cæcum. Its mucous membrane, like

FIG. 1415.



Longitudinal section through junction of appendix with cæcum. × 12.

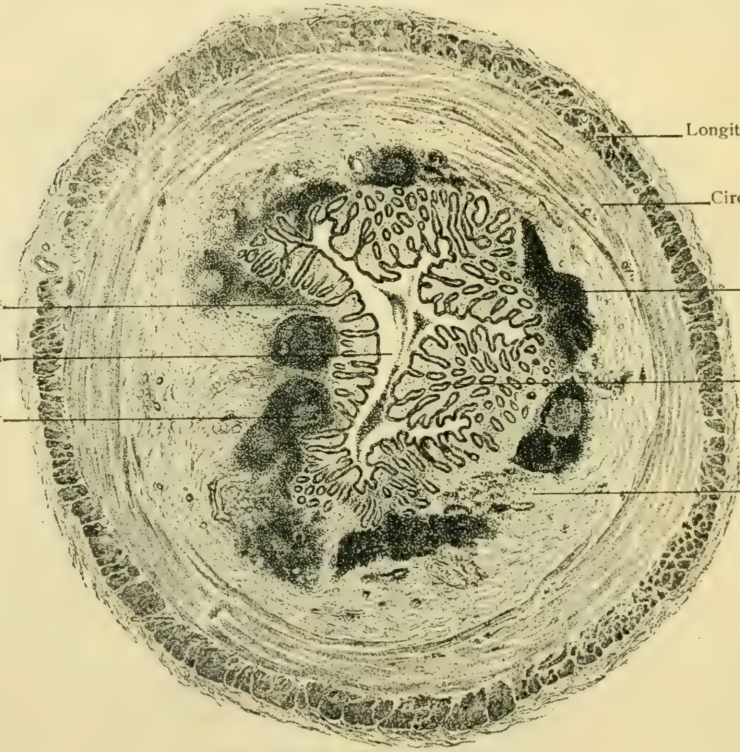
that of the rest of the large intestine, has no villi. This change occurs near the margin of each segment of the ileo-cæcal valve, the villi gradually diminishing and finally disappearing before the free edge of the folds is reached (Langer). The bands of longitudinal muscular fibres always end at the base of the appendix, but the precise manner of their termination is uncertain. According to Struthers,[2] each band bifurcates as it approaches the appendix, and the divisions, meeting those of the others, form a ring around a weak spot close about it. According to Toldt,[3] the ring is formed by the circular layer. The arrangement is not always clear, but we incline to think the latter the more common. The coats of the cæcum are all found in the appendix. The lumen of the latter is small, except near the entrance, and the walls may be in contact. The lymph-nodules of the appendix are exceedingly numerous and large, in places fusing into masses of considerable size, which en-

[1] Deutsches Archiv für Klin. Med., Bd. liii., 1894.
[2] Edinburgh Medical Journal, 1893.
[3] Sitzungsber. Acad. Wissen., Wien, Bd. ciii., 1894.

croach upon the mucosa and its glands to reach almost the free surface. The layer of circular muscular fibres is 1 mm. thick, or about twice the thickness of the longitudinal one. Both layers have interruptions, so that the submucous and subperitoneal layers are in places continuous. This occurs particularly along the insertion of the fold of peritoneum called the mesentery of the appendix.

The **vermiform appendix** (*processus vermiformis*) is a long, slender, wormlike diverticulum from the cæcum, formed of all the coats of the intestine. Its length varies from 1 cm. (⅓ in.) to 24 cm. (9⅓ in.), the average being probably about 8.4 cm.[1] (3¼ in.). Monks and Blake,[2] from the records of 641 autopsies at the Boston City Hospital, give the average length as 7.9 cm. (3 in.), with the extremes as above. Berry finds that the appendix is on the average about 1 cm. longer in

FIG. 1416.



Transverse section of vermiform appendix. × 12.

the male; others find no particular difference. The diameter at the base is 6 mm. and at the apex 5 mm. Its usual origin is from the postero-median aspect of the cæcum. According to Berry, this occurs in more than 90 per cent., the point of origin being 1.7 cm. distant from the end of the ileum. This is very important as showing a relatively fixed point of origin, as the general direction of the appendix is very uncertain. That of the distal half especially is largely a matter of chance. Moreover, the position after death is, except in certain cases, no guide to that during life. The appendix is attached to the cæcum and to neighboring structures by a peritoneal fold to be described later. If this fold be long and narrow, the movements of the appendix are much restricted; if the base of the fold be short and its attachment to the appendix a long one, the appendix is thrown into coils.

[1] Fawcett and Blatchford (for the average length): Proceedings of the Anatomical Society of Great Britain and Ireland, Journal of Anatomy and Physiology, vol. xxxiv., 1900.
[2] Boston Medical and Surgical Journal, November 27, 1902.

This, to a greater or less extent, is the normal condition. There is no doubt that in the great majority of cases the appendix is wholly behind the cæcum, mesial to it, or below it. Monks and Blake found a reference to this point in the records of 572 autopsies. It was "down and in" 179 times, "behind" with no statement of the direction 104 times, "down" 79 times, and "in" 62 times. Thus in almost three-quarters of the cases it was in one of these positions. It ran "up" 52 times, "up and in" 39 times, and "up and out" 29 times. In 9 cases it was "out," "down and out" in 5, and "in pelvis" in 14. It sometimes is attached to the ascending colon by its peritoneal fold, and runs upward with probably accidental inclinations to one side or the other. It may also be found in some of the peritoneal fossæ of the region. In many of the cases marked "down and in" it hung over the pelvic brim. Of 123 cases in which the appendix was covered by peritoneum, and therefore presumably normal, Ferguson[1] found it hanging downward in 11, placed mesially in 18, on the right of the cæcum in 19, and behind it in 75. Total absence of the appendix is extremely rare, but has been observed by ourselves and others.

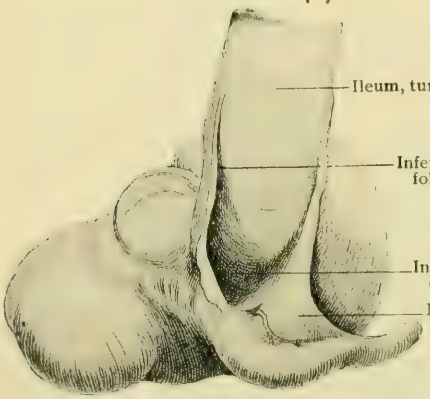
Obliteration of the Cavity of the Appendix.—The adenoid tissue of the vermiform appendix is, as elsewhere, most developed in childhood and tends to atrophy in middle life. Coincident with this atrophy is a tendency (the cause of which is not clear) in the walls to adhere, more or less obliterating the cavity. Ribbert[2] found in 400 specimens more or less obliteration in 25 per cent., and, putting aside those under twenty years, in 32 per cent. After fifty it occurred in more than 50 per cent. He found, however, the obliteration complete in only 3½ per cent. In approximately one-half of the cases it involved only about one-half of the tube. The process usually begins at the closed end of the tube, and is much more frequent in short than in long appendices. Zuckerkandl[3] observed more or less obliteration in 23.7 per cent. of 232 specimens, the process being nearly or quite complete in 13.8 per cent. Ribbert saw the process beginning in childhood, but never under five years. Fawcett and Blatchford[4] found the appendix pervious 196 times in 221 cases, and 91 of the pervious ones were from those over fifty years. We agree with them that much more conclusive evidence is needed to establish the existence of a special atrophy of the appendix in old age or after middle life.

Peritoneal Relations.—The cæcum, being originally an outgrowth from the convex side of the primitive intestinal loop, is completely covered by peritoneum and has no mesentery, since the mesentery of the ileum passes directly to the colon. The appendix, being the original end of the cæcal pouch, is consequently also completely invested with peritoneum. When the ascending colon has come to lie in the right flank, the posterior layer of its mesentery degenerates into areolar tissue, fusing with that resulting from the degeneration of the parietal peritoneum behind it, and by the same process the back of the colon is attached by areolar tissue to the abdominal wall behind. This condition almost always ends a short distance above the cæcum. It is far more common to find the lower third of the ascending colon with peritoneum on its posterior surface than to find none on the upper posterior part of the cæcum. This condition, indeed, does occur, we having seen it at birth; but it is very exceptional. From the preceding facts it follows that the cæcum and the appendix can have no mesentery in the strict sense; nevertheless, the term *mesentery of the appendix*, or *meso-appendix* (**mesenteriolum processus vermiformis**), is applied to an almost constant fold of peritoneum, presumably caused by the artery of the appendix, which usually is attached to nearly the entire length of that organ. Authorities differ widely as to how far the line of attachment extends along the appendix. Beyond question it is very variable. According to Monks and Blake, it extends nearly or quite to the end in fully one-half of the cases, and in most of the other half it reaches or passes the middle of the appendix. Its general appearance is triangular, but, according to both Jonnesco[5] and Berry,[6] with whom we agree, it is more properly described as quadrilateral. One side runs

[1] American Journal of the Medical Sciences, 1891.
[2] Virchow's Archiv, Bd. cxxxii., 1893.
[3] Anat. Hefte, Bd. iv., 1894.
[4] Proceedings of the Anatomical Society of Great Britain and Ireland, Journal of Anatomy and Physiology, vol. xxxiv., 1900.
[5] Hernies internes rétro-péritonéales, Paris, 1890.
[6] The Cæcal Folds and Fossæ and the Topographical Anatomy of the Vermiform Appendix, Edinburgh, 1897.

along the proximal half or even the whole length of the appendix, one is free, and the other two are attached to the left side of the mesentery and to the cæcum respectively. These latter are not readily distinguished from each other; hence the triangular effect. The artery of the appendix enters the fold on the back of the cæcum, and runs at first from 5 mm. to 1 cm. distant from its free edge, which gradually approaches it. Although the fold may terminate before reaching the end of the appendix, it does not follow that the whole of the latter is not enclosed in peritoneum, since under normal circumstances it always must be. The course, shape, and size of the meso-appendix are very irregular. It is almost invariably so short that the proximal half of the appendix is thrown into coils. We have seen this fold attached to the right side of the mesentery, as well as not attached to it at all. Sometimes it runs upward along the posterior part of the left side of the colon, so that the appendix is vertical; at other times it is attached to the floor of the iliac fossa; and very rarely it is wanting. In the female adult a secondary fold can very often, but by no means always, be traced from the meso-appendix to the broad ligament. This fold is probably due to the persistence of one which in the fœtus often connects the appendix or cæcum with the early ovary and the oviduct. The lymph-node which the meso-appendix is said to contain we have seldom found. It happens frequently that, from pathological causes by which adhesions have changed the peritoneal relations, the appendix lies behind the peritoneum. Ferguson found it so 77 times in 200.

FIG. 1417.



Cæcum from inner side and below.

Pericæcal Fossæ. — An indefinite number of fossæ or pouches, all more or less variable, are to be found about the cæcum. The two following are usually demonstrable, although not so constant as held by some authors.

The **superior ileo-cæcal fossa**[1] (Fig. 1414) is roofed in by a peritoneal duplicature, the *superior ileo-cæcal fold*, which, starting from the right surface of the mesentery, curves over the end of the ileum from behind forward. The attached border, in which the ileo-colic artery lies, runs along the colon just where it joins the ileum, and is usually continued forward down onto the front of the cæcum for a short distance. The pouch between this fold above and the end of the ileum below opens to the left, but if the ileum be distended, the free edge of the fold is so closely applied to it that the fossa is easily overlooked. The depth of the fossa may reach 3 cm. It is most distinct in infants and frequently obliterated in middle life, although careful examination often reveals a small fold and recess that may be overlooked. Berry found this fossa absent in 12 of 100 cases, all of the 12 being over forty years.

The **inferior ileo-cæcal fossa**[2] (Fig. 1417) is less constant and much more complicated than the preceding. Its practical importance is greater, since it may contain the appendix. To display it the ileum must be drawn upward and the appendix downward and to the right; the cæcum may or may not require to be displaced to the right or inverted. This fossa is situated in the entering angle formed by the end of the ileum joining the cæcum, and is bounded on the right by the first part of the appendix. The meso-appendix shuts it in behind, and in front it is covered by the *inferior ileo-cæcal fold*.[3] The latter, which usually joins the

[1] There is much to be said in favor of the term *ileo-colic*, since the pocket lies at the angle of the ileum and colon. It, however, so frequently extends downward to the front of the cæcum that the more usual nomenclature is here adopted.
[2] Known also as the *ileo-colic fossa*, the *ileo-appendicular fossa*, etc.
[3] This is the "bloodless" fold of Treves or the ileo-appendicular fold of Jonnesco.

meso-appendix, is in its conventional form described as having four sides: a superior on the ileum, a right one on the cæcum, an inferior joining the appendix or the meso-appendix, and a free concave one looking towards the left and overhanging the entrance to the fossa, which may be nearly 4 cm. (1½ in.) in depth. The fold usually contains only small vessels, and has been described as "bloodless." It sometimes contains muscle-fibres passing between the ileum and cæcum. The size as well as the formation of this pocket is very variable. When we consider the extreme variability of the meso-appendix which is concerned in its typical formation, it is manifest that such must be the case. Sometimes the meso-appendix is in no way connected with it, only a small fold of peritoneum passing from the ileum to the cæcum at the side most removed from the mesentery. Berry found this fossa in 74 per cent.

The Retro-Colic Fossa.—In the great majority of cases the posterior surface of the cæcum lies free in the abdominal cavity, covered by its original peritoneum. At a variable distance from it the back of the colon becomes adherent to the posterior abdominal wall and to the front of the right kidney; hence there is, or may be, especially if the colon be drawn away from the wall, a fold on either side stretching from the gut to the wall. These are the *ligaments of the colon*, the *external* and the *internal*. The former runs outward and downward from the side of the colon along the abdominal wall, or perhaps across the lower end of the kidney, and presents a free concave border overhanging a pouch running upward and outward. The internal or mesian fold is the more often distinct, and is formed chiefly by the insertion of the mesentery. According to its degree of development, the free falciform edge overhangs a pouch, looking downward and more or less to the right. The fold may be continued downward either to the right or to the left. In the former case it may form a pocket, of which the lower end opens upward. It is clear, therefore, that with both these folds well developed a *retro-colic fossa* exists, which is shown when the cæcum is turned up. Its greatest depth is in the middle behind the colon, and it is continued downward on either side under the folds caused by these ligaments. Should either ligament be wanting, there can be no fold on that side. Some authors have thought it best to describe an external and an internal fossa under each of the ligaments, of which the internal is the more frequent; it is more simple, however, to describe only one. The fossa may be subdivided by a median fold. Very often there is no definite fossa at all. The internal part is more commonly well developed than the external.

The **subcæcal fossa** is an uncommon pouch, sometimes small and sometimes large, situated above the middle of the iliac fossa. It seems to be due to an irregular development of the iliac fascia, which forms a pocket in itself, with the mouth above, guarded in front by a semilunar fold. The fossa is lined by the parietal peritoneum. It may unite with the inner fold of the retro-colic fossa, or the two may exist at the same time. It may contain the appendix, even a part of the cæcum, or, according to Jonnesco, coils of the small intestine.

Blood-Vessels.—The *artery* supplying the cæcum is the ileo-colic, a branch of the superior mesenteric artery, which sends to it both an anterior and a larger posterior branch, which ramify downward over the front and back of the cæcum. A large branch from the posterior division runs between the folds of the posterior retinaculum; less constantly a smaller vessel courses in the anterior one. The segments of the ileo-cæcal valve are very vascular. The *artery of the vermiform appendix* arises from the posterior division of the ileo-colic, crosses the back of the ileum, and runs in the fold of peritoneum to the end of the appendix. The *veins* of the cæcum are arranged on much the same plan as the arteries. That of the appendix is relatively more important, receiving tributaries from the front and the back of the cæcum. It passes behind the end of the ileum to the ileo-colic vein.

The **lymphatics** are divided into a posterior and an anterior set. The former empty into small nodes on the back of the cæcum beneath its peritoneal covering. The anterior ones are in or near the fold between the cæcum and colon. The appendix contains a large lymph-sinus at the base of the follicles. Lymphatics pass through the interruptions of the muscular layer. They may enter a node in the peritoneal fold in the angle between the cæcum and ileum. There are several possible communi-

cations : one with nodes in the mesentery ; one with nodes on the left of the ascending colon behind the peritoneum ; one with nodes of the iliac fossa ; and, in the female, one with the system of the ovary. There is a constant lymph-node at the angle between the ileum and colon.[1]

The **nerves** supplying the cæcum and appendix are derived from the superior mesenteric plexus. Their mode of distribution within the gut has already been given (page 1643).

Development and Growth.—At birth and for some years after the cæcum is very small and the fœtal or cornucopia shape is more frequent than later. The appendix is relatively rather long. In eleven cases below ten years Berry[2] found the average length of the cæcum 28 mm. and the breadth 37 mm. In eighteen cases he found the average length of the appendix 74 mm. (2⅞ in.). Ribbert gives the following lengths of the appendix : at birth, 34 mm. ; up to five years, 76 mm. (3 in.); from five to ten years, 90 mm. (3½ in.).

At birth the cæcum is usually higher than in the adult, since it has not descended to its permanent position and the adhesion of the mesentery of the ascending colon has not occurred in the lower part of the flank. It is often rather above the anterior superior spine of the ilium. In five of about thirty-five observations on young children, mostly newly-born, it was so free from fixed attachment that it could hardly be said to have any definite position.

THE COLON.

The *ascending colon* extends from the cæcum to the under side of the liver, where it makes a sudden bend—the *hepatic flexure* (flexura coli dextra)—and becomes the *transverse colon*, which crosses the abdomen to the *splenic flexure* (flexura coli sinistra) at the spleen, whence, as the *descending colon*, it passes to the crest of the ilium. From that point to the middle of the third sacral vertebra it is known as the *sigmoid flexure.* The three bands of the colon, or *tæniæ coli*, formed by accumulations of longitudinal fibres, are each about 1 cm. broad. Their disposition in the walls of the gut is difficult to follow and is not constant. The following arrangement is probably the most usual. In the ascending colon one is in front and two behind, one of the latter being near the outer and the other near the inner aspect. On reaching the transverse colon, the anterior becomes the inferior, while the external becomes the superior, receiving the attachment of the transverse mesocolon. The internal also lies on the upper surface, but behind the preceding. On the descending colon they resume their original positions, but tend to grow indistinct. They are still more so in the sigmoid flexure, and before the rectum is reached there are but two bands, an anterior and a posterior, of which the latter is the stronger. The interior of the colon shows the sacculated condition, but there are no folds or valvulæ conniventes like those of the small intestine. The solitary lymph-nodules continue, much like those of the jejuno-ileum.

Relations.—The **ascending colon** is in the right flank against the psoas and quadratus lumborum, but does not overlap the latter unless greatly distended. It lies in front of the lower end of the right kidney, projecting but little beyond its outer border, with the second part of the duodenum on its inner side. It ends with the hepatic flexure, which makes a large impression on the under side of the right lobe of the liver directly anterior to the kidney. It is often completely covered in front by the small intestine.

The **transverse colon** is suspended between its beginning, the hepatic flexure, and its end, the splenic flexure, like a festoon, forward and downward ; for the ends are near the back of the abdominal cavity. The splenic flexure, in front of the lower part of the spleen, is both higher and more posterior than the hepatic one. The transverse colon is covered above and in front by the greater omentum. It runs along the liver, touching the gall-bladder and the greater curvature of the stomach, around which it ascends to the spleen. The splenic flexure may or may

[1] Lockwood : Proceedings of the Anatomical Society of Great Britain and Ireland, Journal of Anatomy and Physiology, vol. xxxiv., 1900.

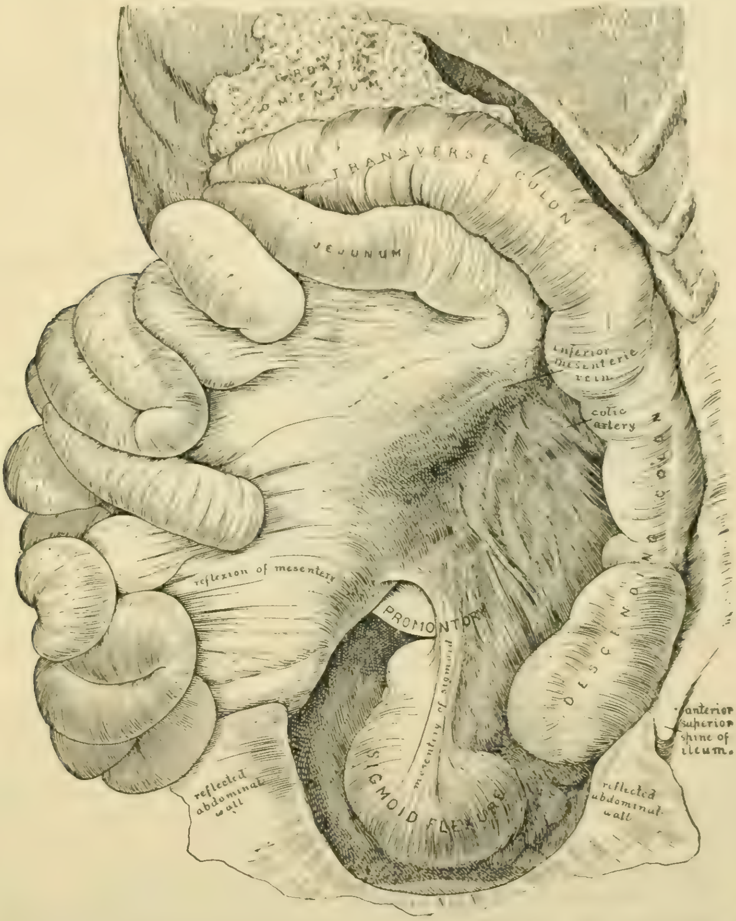
[2] Anat. Anzeiger, Bd. x., 1895.

not rest against the under side of the diaphragm, according to its distention and that of the stomach. It rests behind and below on the small intestine. It may or may not be in immediate relation to the tail of the pancreas.

The **descending colon** descends partly in front, but still more external to the kidney, and after passing the kidney rests wholly on the quadratus lumborum. Although more externally placed than the ascending colon, it does not usually project beyond that muscle. It may be very much contracted and sacculated.

The **sigmoid flexure** (**colon sigmoideum**), the continuation of the large intestine, begins at the crest of the ilium as a loop of very varying length, which is attached by

FIG. 1418.



Left side of abdomen; small intestine turned to right, exposing mesentery, mesocolon of descending colon, and mesosigmoid.

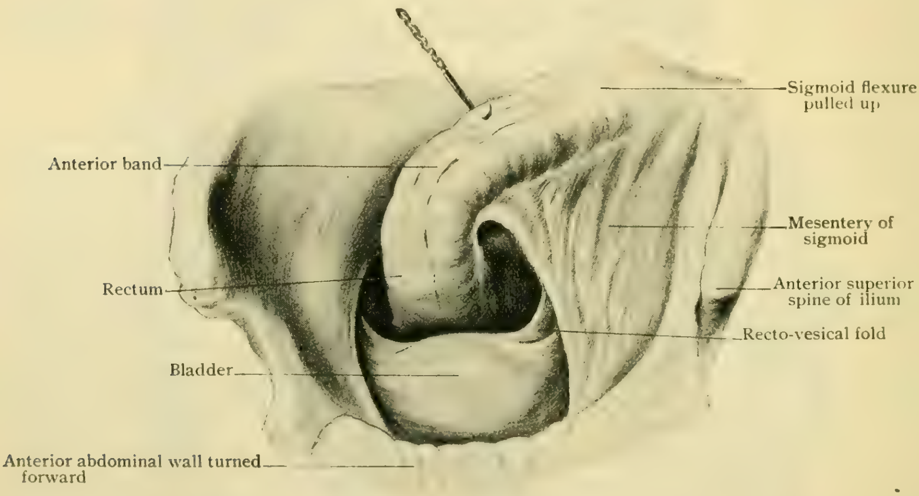
a mesentery, and ends at the middle of the third sacral vertebra. Its usual length is from 25–56 cm. (10–18 in.), but is occasionally much longer. While it is true that the gut does not always become free at the crest of the ilium, but may descend, bound down closely, to the iliac fossa for some distance, it is best to regard the sigmoid flexure as beginning at a definite although arbitrary point rather than at the less certain one at which the gut really has a mesentery. Moreover, there is no great inaccuracy in the statement that this generally occurs at the crest of the ilium or just below it. The simplest form of the sigmoid flexure is a loop. If it be a small one, it usually is made of the last part of this section of the gut; very often the first part is but slightly free while the last part is very much so. Short sigmoid flexures,

especially with short mesenteries, can hardly vary much from a simple loop ; under opposite conditions, however, they may present the most diverse forms, so that a definite shape can hardly be assumed. The M-form is common. We have seen the sigmoid disposed in three parallel vertical folds occupying all of the left iliac fossa and overhanging the true pelvis. As the sigmoid flexure descends along the sacrum it usually curves to the right and crosses the median line.

Peritoneal Relations.—The lower part of the **ascending colon** is very often, for one or two inches, completely surrounded by serous membrane. The ligaments of the colon (described with the retro-colic fossa, page 1667) occur more or less well marked at the line where the peritoneum leaves the posterior wall. Above this the colon is connected by areolar tissue to the kidney. Occasionally the colon is adherent as far as the cæcum. The non-peritoneal portion of the upper part of the ascending colon equals about one-third of its circumference.

The **transverse colon** is attached to the transverse mesocolon and otherwise completely surrounded by peritoneum. The transverse mesocolon, after attaining its permanent condition, arises along the back of the abdomen from one kidney to

Fig. 1419.



Sigmoid flexure and rectum; sigmoid has been displaced upward to show its mesentery.

the other. It crosses the front of the right kidney, the second part of the duodenum, and passes along the lower border of the pancreas above the duodeno-jejunal flexure, to end on the left kidney. Sometimes in the left part of its course its origin rises onto the superior anterior surface of the pancreas. Its greatest breadth —*i.e.*, the distance from its origin to insertion—is at the middle, and varies from 10–15 cm. The posterior layer of the greater omentum fuses with it. The *phreno-colic ligament*, which runs inward, shelf-like, from the left abdominal wall under the spleen, although in acquired relation with the mesentery of the transverse colon, is really a part of the greater omentum. The latter hangs down from the transverse colon over the small intestine, but its relation to the colon is not the same throughout. On the right it is fused with the peritoneum of the anterior surface of the gut and leaves it at the lower border. On the left it leaves the upper surface of the colon, or even the transverse mesocolon, before the latter reaches the gut. Thus the line at which it leaves the intestine rises gradually from right to left.

The **descending colon** is usually uncovered posteriorly by peritoneum. According to Lesshaft,[1] whose results have been generally accepted, it has more or less of a mesentery once in six times. According to Symington,[2] the mesenteries

[1] Reichert and Du Bois-Reymond's Archiv, 1870.
[2] Journal of Anatomy and Physiology, vol. xxvi., 1892.

thus found are due to a displacement of the peritoneum, which is but loosely attached. True mesenteries are probably less frequent.

At the **sigmoid flexure** the peritoneum usually begins to surround the gut, although the point at which this commences may be much lower. In the former case the line of origin of the mesentery descends tolerably straight to the middle of the third sacral vertebra, where it ends. The gut may, however, be pretty closely bound down to the iliac fossa as far as the true pelvis over the posterior border of the obturator foramen, in which case the line of attachment runs thence backward along the border of the true pelvis until it crosses the sacro-iliac joint, after which it descends across the sacrum. There may, of course, be an indefinite number of variations between these extremes. The attachment to the sacrum is usually near the median line over the second and third vertebræ, but it may diverge to either side of it. Variation also exists as to the point at which the mesentery ends. The greatest breadth—*i.e.*, from origin to insertion—of the latter is usually found in the part which springs from the first sacral vertebra. It is, on the average, about 9 cm., rarely less than 5, not more than 16; exceptionally it may be as much as 25 cm. With a long loop it is, of course, relatively narrow at its origin.

The **intersigmoid fossa** is an inconstant small peritoneal pouch, present about three times out of four, on the under side of the mesentery of the sigmoid flexure, which is shown by throwing the loop upward and to the right. It is obviously due to the failure of the sigmoid mesentery to unite completely with the peritoneum of the posterior wall, and consequently is under the edge of the part that fails to unite, lying usually just above the true pelvis near the common iliac artery. The orifice of the pocket is very likely to be circular, with a diameter of from 1–3 cm., in most cases nearer the lower figure. The pouch may be quite rudimentary, or may extend up like a tunnel between the layers of peritoneum for an inch or two, or exceptionally for a greater distance.

Development and Growth.—The length of the intestines, and especially of the colon, is, according to Treves, singularly constant at birth. He found the average length of the small intestine about 287 cm. (9 ft. 5 in.) and that of the large about 56 cm. (1 ft. 10 in.). It is remarkable that while during the first two months the small intestine grows at the rate of about two feet a month, the large intestine remains of the same length for three or even four months. This is due to the fact that during this period the large intestine grows at the expense of the sigmoid flexure, which at birth forms nearly one-half of the whole, while at four months it has assumed approximately its permanent proportions (Treves). After this the growth of both small and large intestine is extremely irregular, as shown by the following table:

Observer.	Age.	Small Intestine.	Large Intestine.
Dwight.	10 months.	670 cm.	78 cm.
Dwight.	10 months.	435 cm.	90 cm.
Treves.	1 year.	. . .	76 cm.
Dwight.	3 years.	490 cm.	84 cm.
Treves.	6 years.	. . .	91.5 cm.
Treves.	13 years.	. . .	107 cm.

As the sigmoid flexure is relatively large in the infant and the pelvis very small, the convexity of the loop lies in the right side of the abdomen.

Variations.—The mesentery of the small intestine and of the ascending and the transverse colon may remain attached only at the origin of the superior mesenteric artery, giving the condition known as *mesenterium commune*. The ascending colon may, on the other hand, be so long as to make secondary folds. Curschmann[1] has seen its mesentery long enough to be twisted. The transverse colon may be short, wanting one or both flexures. In the latter case the ascending and the descending colon are almost like the sides of an inverted V. Probably much more often the transverse portion may be too long and descend in the middle like an M, with the middle point at the pelvis. A fold is more common at the left than the right. A double fold of the transverse colon has been seen. This part of the gut, when over large, may decidedly diminish the area of the liver dulness. The descending colon may also present folds, but an immense sigmoid flexure, which usually is accompanied by great length of the large intestine, is more common. The convexity of this fold may reach to the transverse colon or to the cæcum. Sometimes the sigmoid flexure consists of two successive folds.

[1] Deutsches Archiv für Klin. Med., Bd. liii., 1894.

Blood-Vessels.—The *arteries* of the colon are derived from the superior and the inferior mesenteric. The former supplies the cæcum, the ascending and the transverse colon, and a varying amount of the descending colon. The supply of the latter is completed by the inferior mesenteric, which is also distributed to the sigmoid flexure. The general plan includes a series of anastomoses between neighboring branches, by which long arterial arches run near the border of the gut, to which they give off irregular twigs. There is no system of straight vessels as in the greater part of the small intestine. In the sigmoid flexure there is a recurrence of the superimposed arches, which may be three in number. The superior hemorrhoidal branch of the inferior mesenteric artery runs in the last part of the mesentery of the sigmoid, and often divides in it into two branches, which run side by side on the back of the gut towards the rectum. The *veins* are disposed much the same as the arteries, but with a system of straight vessels from the intestine.

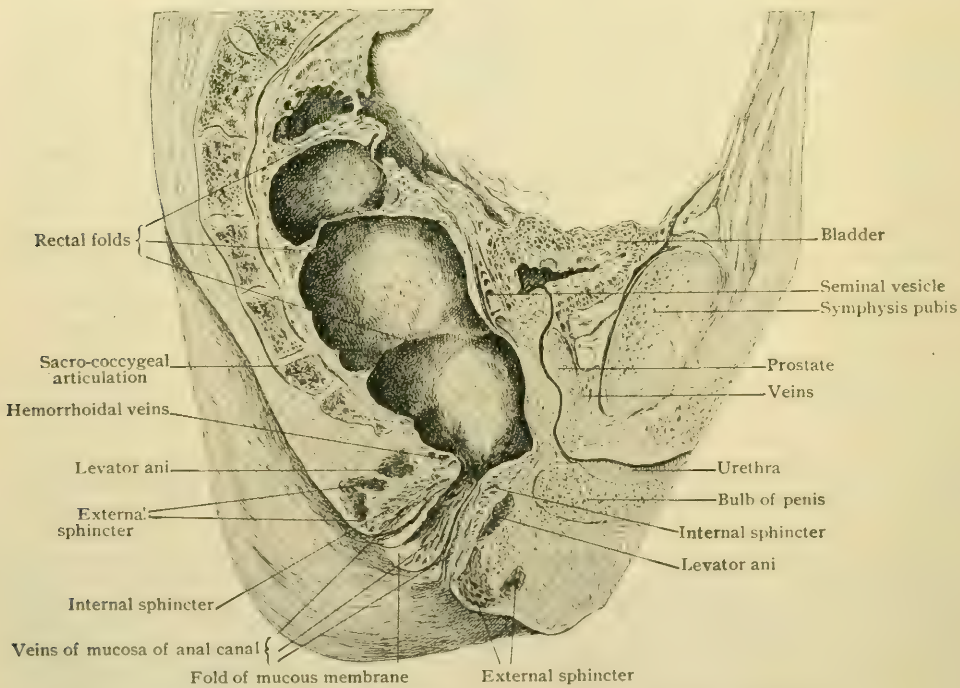
The **lymphatics,** which are many, empty into lymph-nodes on the posterior wall of the abdomen, which are a part of the same system as those of the small intestine.

The **nerves** are from the superior and inferior mesenteric plexuses, which are derived chiefly from the solar and the aortic plexus respectively.

THE RECTUM, ANAL CANAL, AND ANUS.

The Rectum.—The rectum begins at the middle of the third sacral vertebra, the point at which usually the mesentery that restrains the sigmoid flexure terminates. It was formerly described as beginning at the left sacro-iliac joint, but this division, which is unwarranted, has now become obsolete. The rectum descends

FIG. 1420.



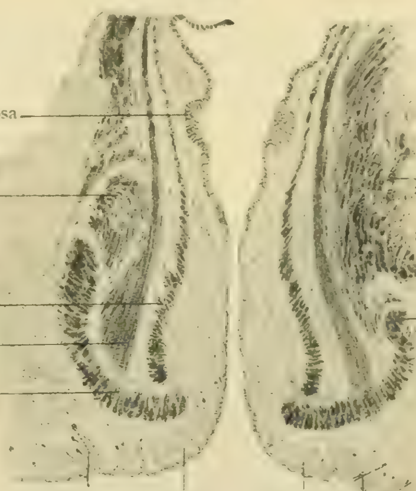
Sagittal section of pelvis passing through rectum, anal canal, bladder, and urethra.

along the hollow of the sacrum and coccyx, passes the point of the latter, and continues until it reaches the lower and back part of the prostate gland in the male or the vagina in the female. Its length is about 12.5 cm. (approximately 5 in.). The gut is then continued by the *anal canal*, sometimes called the *sphincteric portion* of

the rectum, situated in the thickness of the pelvic floor, and directed downward and backward, making a sharp angle with the rectum proper.

The *rectum proper*, having passed the tip of the coccyx, rests on the levator ani muscle, although separated from it, as well as from the sacrum and coccyx, by the dense rectal fascia. The rectum, although not exhibiting the pouching seen in the colon, is sacculated, presenting, when distended, usually three dilatations, of which the lowest and largest, called the *ampulla*, may measure 25 cm. (9⅞ in.), or even more, in circumference. The saccules are separated by deep creases, passing about two-thirds around the gut, caused by a folding in of all the coats internal to the two bands of longitudinal muscular fibres. The folds form the *valves of the rectum*, to be described with its interior. In the male the ampulla extends against the back of the prostate and the lower part of the seminal vesicles and the terminal parts of the vasa deferentia, to all of which it is connected by areolar tissue. A pocket of peritoneum intervenes higher up, the walls of which, however, come in contact when the hollow organs are distended. In the female the end of the ampulla lies against the posterior wall of the vagina from about opposite the level of the os uteri to the junction of the middle and lower thirds. There is above this a fold of peritoneum corresponding to that of the male.

FIG. 1421.



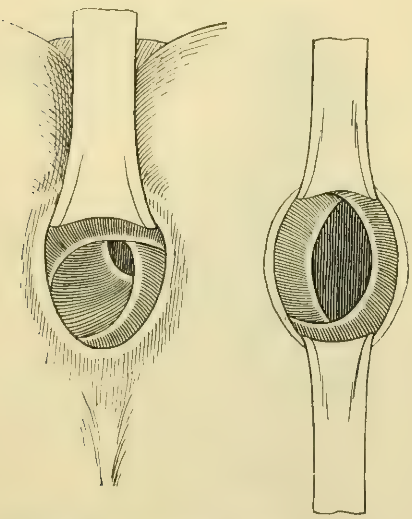
Frontal section through anal canal.

The Anal Canal.—This part of the large intestine (**pars analis recti**) is situated in the thickness of the pelvic floor and extends downward and backward. It differs from the rest of the intestinal canal in having no lumen under ordinary circumstances, when the sphincters surrounding it are contracted. The **anus** is the very vaguely used name of the termination of the anal canal. It is deeply situated between the nates, especially in the female ; its distance from the tip of the coccyx, variously stated by different observers, may be said to be about 5 cm. (2 in.). Much confusion has arisen from the difficulty of defining the lower end of the anal canal, since the skin, which is puckered up by the external sphincter and the corrugator cutis ani, somewhat resembles mucous membrane, so that the canal appears longer than it really is. The anatomical boundary, the *ano-rectal* groove, the so-called *white line* of Hilton, is a slight zigzag furrow, usually to be seen on the living and not on the dead. It lies a little above the lower limit of the internal sphincter, which, covered by dilated veins, projects towards the potential lumen above the external sphincter, and is 1 cm. or more within what, on a superficial examination, would be called the anus. When the dissected rectum is laid open, much is evidently a part of the skin which during life is drawn into the canal by the contraction of the muscles ; hence the length of the canal is very variously stated. Seldom does it

measure as much as 15 mm. from its upper end to the ano-rectal groove ; probably this distance is usually about 1 cm., while what may practically be called the canal is twice as much, or even more. It is longer in men than in women. In the male the beginning of the anal canal is near the lower part of the prostate and the membranous urethra, at a point from 3.5–4 cm. in front of and somewhat lower than the tip of the coccyx. Lower still, the bulb of the urethra is separated from the anal canal by the pyramidal mass of connective tissue constituting the *perineal body.* The latter is of greater importance in the female, and separates the anal canal from the lower part of the vagina and from the vulva. The moist and dark skin which is puckered up to form the continuation of the anal canal is at first very thin, but gradually assumes the appearance of ordinary integument. The so-called *anal glands* surrounding the anus are of two kinds, both of which have their orifices in this skin. Those nearest to the boundary line are sebaceous follicles, and external to them is a zone of large sweat-glands. Just at the termination of the skin apparently forming the end of the canal there is, especially in the male, a considerable development of hair.

Structure of the Rectum.—The **mucous coat** is thick and vascular, and corresponds in its general histological details with the mucosa of other parts of the large intestine. The glands of Lieberkühn, however, are exceptionally large, attaining a length of .7 mm. The muscularis mucosæ is better developed than in the colon. The *rectal valves* (**plicæ transversales recti**) are two or three folds, exceptionally four or five, projecting like transverse shelves into the cavity when it is distended, and hanging loose when it is not. They are semilunar in shape, with the greatest breadth from the attached border to the free edge, ranging from 1 cm. to more than 3 cm. They correspond to, or rather are the causes of, the constrictions between the saccules. They contain all the coats of the gut, except that, chiefly on the posterior wall, some of the longitudinal muscle-fibres pass outside of them, thus securing the fold. In large folds there is an accumulation of the circular fibres. These folds tend to be effaced in the isolated and opened rectum, but they are unquestionable, being shown by casts and frozen sections, and in both the living and the dead body when placed in the knee-chest position with the rectum cleared of fæces and distended with air. They are placed laterally, and have in common that their points cross the middle line, although not symmetrically, extending more onto the front than the back. According to the usual arrangement, the lowest, which is also the smallest, projects from the left ; the second, the largest, from the right ; and the third from the left. The first is about 2.5 cm. (1 in.) above the anal canal and the second about as much higher. If the first—as often happens—be wanting, the second is not necessarily any lower. The third is usually at about the same distance above the second, but is subject to greater variations, since the two may be very near together.[1] The *columns of Morgagni* are a series of permanent vertical folds of mucous membrane passing from the anal canal upward into the rectum. The number of these folds varies from five to considerably more than ten, which latter number is perhaps about the average. The length of the folds is in most cases from 1–2 cm., but some are considerably longer. They are broad and highest at their anal end, or base, from which they diminish to the upper end, a transverse cut near the lower end showing them to be triangular on section. The *valves of Morgagni* are semilunar folds of the mucous membrane connecting the bases of the columns of the same name, and forming with them a number of

FIG. 1422.



Folds of rectum seen after dilatation. (*Otis.*)

[1] Otis : Anatomische Untersuchungen am menschlichen Rectum, Leipzig, 1887.

pouches opening upward. They are situated in the anal canal at the upper part of the internal sphincter. The mucous membrane of the rectum is thrown into a series of longitudinal folds. These are easily effaceable, although some are continuous with the columns of Morgagni.

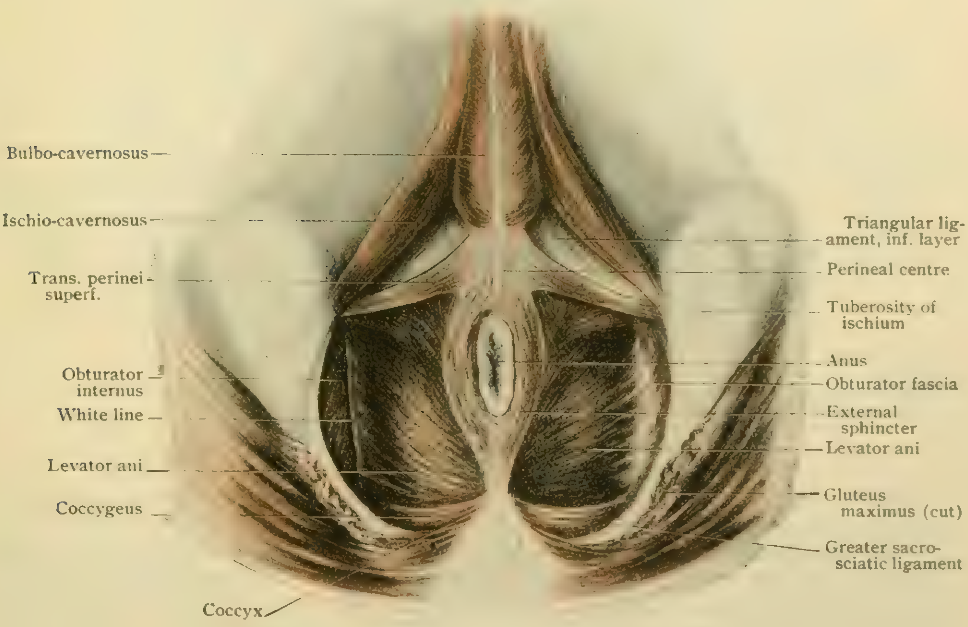
The **submucous coat** is lax, allowing the mucous membrane to be readily displaced, but at the lower end of the anal canal the latter is firmly attached to the muscles.

The **muscular coat** of the rectum is thicker than that of the colon, reaching to 2 mm. The thickening is greatest in the layer of the circular fibres. The longitudinal ones, although forming a continuous layer, are for the most part collected front and back into the two bands already mentioned, of which the posterior is the larger and the more concerned in bridging over the folds. The internal sphincter is but an hypertrophy of the circular muscles, while the external sphincter is a muscle of the perineum. It has been thought advisable to describe here together the muscles and some of the fasciæ of the rectum and anus, including some that are largely extrinsic.

THE MUSCLES AND FASCIÆ OF THE RECTUM AND ANUS.

The **levator ani** (Figs. 1423, 1424) arises from the back of the body of the pubes, about midway between the upper and lower border, very close to the middle line, and thence, from the "white line" formed by the splitting of the pelvic fascia, as far as the spine of the ischium. The anterior fibres from the pubic bone pass below the prostate, some going to its capsule, as a strong muscular bundle to the central

Fig. 1423.



Muscles of pelvic floor and perineum from below.

point of the perineum and the front and sides of the rectum, in which some of them end. The remainder of this set passes with the fibres from the white line to the side of the coccyx and to a fibrous band (**ligamentum anococcygeum**) running from it to the anus. This latter part of the muscle is thinner and more transversely placed than the former. In the female the pubic portion sends some fibres to the vagina and some around it to the central point of the perineum. The fibres, for the most

part in both sexes, pass by the rectum so as to compress it, although some enter its walls and mingle with those of the sphincters.

Nerve.—A branch from the sacral plexus (sometimes there are more than one) runs to the levator ani on its upper surface. The fibres come from the third and fourth sacral nerves. According to some, the muscle also receives fibres from the inferior hemorrhoidal branch of the pudic nerve.

The **coccygeus** (Fig. 1424), a triangular muscle arising from the spine of the ischium and inserted into the border of the coccyx, is in the same plane and practically continuous with the levator ani. The two muscles of both sides have been well called the *diaphragm of the pelvis*. They form a funnel-like structure with the walls converging downward to the anal canal, and an anterior opening for the prostate in the male and the vagina and urethra in the female.

FIG. 1424.

Muscles of pelvic floor from within; section passed to left of mid-line.

Nerve.—The muscle receives branches from the fourth and fifth sacral nerves and perhaps from the first coccygeal.

The **external sphincter ani** (Fig. 1423), situated beneath the skin and carried up into the puckering at the anus, is a flat oval muscle composed of striated fibres surrounding the end of the rectum. It arises from the tip of the coccyx, from the skin over it, and from a raphe extending from it to the anus. The fibres diverge on either side to enclose the anus, meeting in front of it at the central point of the perineum (page 1917), where they mingle with other muscles which meet at that point. Some of the inner fibres completely encircle the anus. In the female some fibres decussate with those of the sphincter vaginæ. This sphincter is "external" in two senses: it is nearer the outer surface than the internal sphincter and also surrounds it.

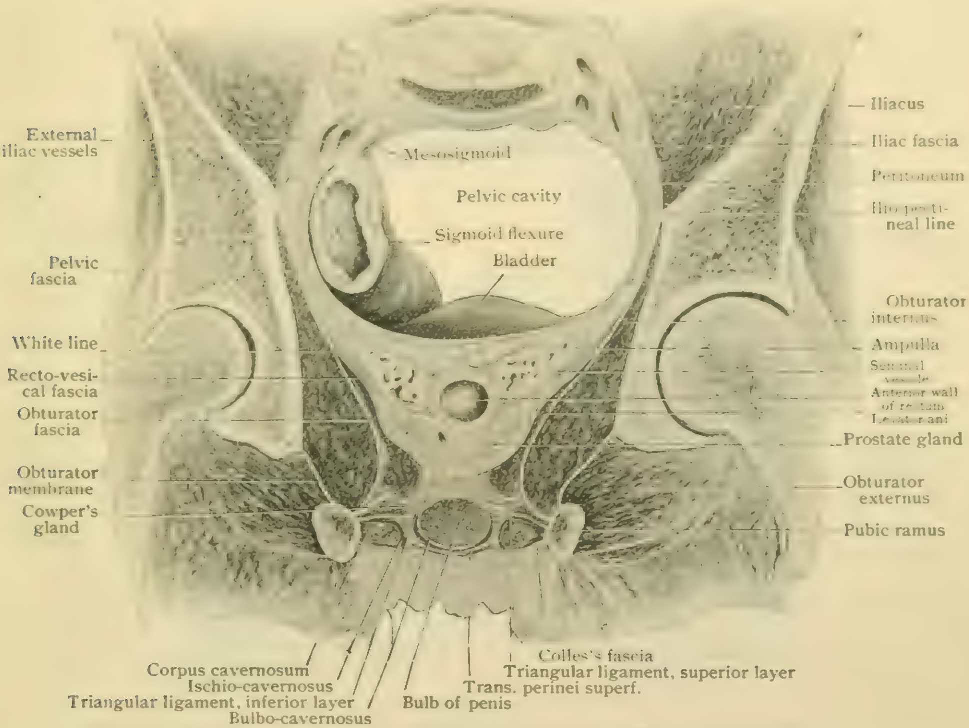
Nerve.—It is supplied by branches of the fourth sacral and of the inferior hemorrhoidal nerve.

The **internal sphincter ani** (Fig. 1421), composed of involuntary muscular fibres, is a thickening of the circular layer of the rectum, which becomes marked at the beginning of the anal canal. It surrounds the latter for a distance of from 2.5–3 cm., and is about 4 mm. thick.

Nerves reach the internal sphincter through the sympathetic system. Very probably some of them come directly from spinal nerves.

Accessory Muscular Bundles.—As they reach the anal canal, the longitudinal fibres of the rectum send bundles to the skin, which gain their destination by coursing through those of the external sphincter; the longitudinal muscle-fibres of the mucous coat, becoming enlarged, pass in the same way between the bundles of the internal sphincter. No important accessions are received from the levator ani. The longitudinal muscular fibres of the rectum, moreover, enter into connection with the areolar tissue of the pelvic fascia between the peritoneum and the levator ani, and perhaps with the latter also. Various bundles of muscle-fibres, apparently arising

FIG. 1425.



Frontal section of pelvis passing just behind the bladder, posterior surface.

from the pelvis, mingle with those of the rectum. The *recto-coccygeus* of Treitz arises from the anterior surface of the coccyx above the pelvic floor and mingles with both the longitudinal and circular fibres at the back of the rectum. It is said to consist of striated fibres at its origin. Bundles of fibres are described as arising from the fascia on the deep surface of the *transversus perinei profundus* muscle and passing to the front of the gut.

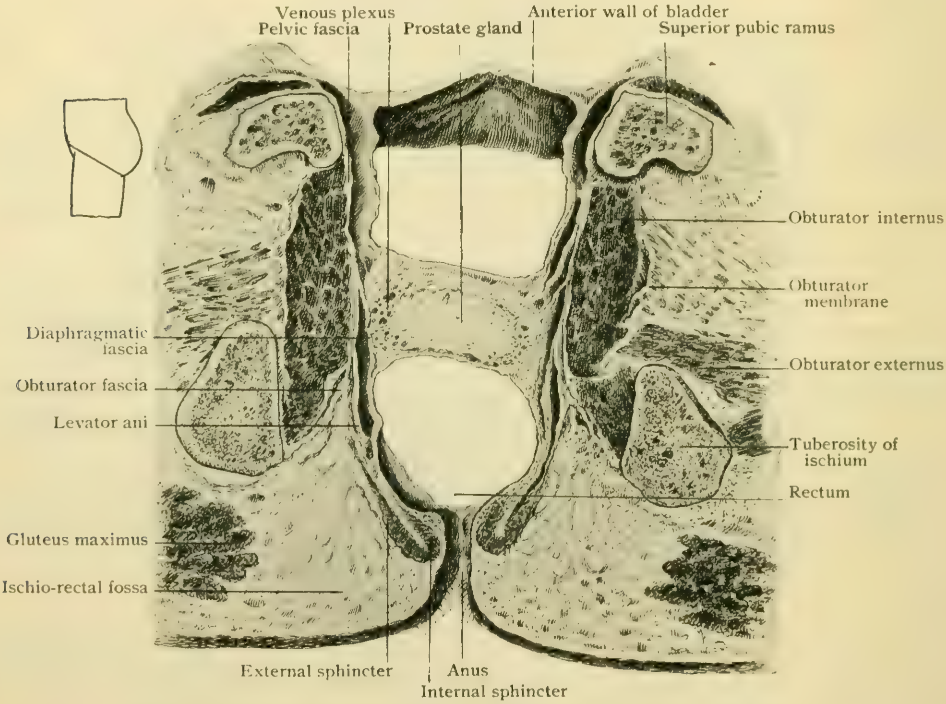
The *corrugator cutis ani* is a small system of muscular fibres radiating from the submucous tissue at the anus to the deep side of the skin, which it tends to pucker.

Actions.—The function of the sphincters is to keep the anal canal closed. They differ, inasmuch as the external, although mostly acting automatically, is under the control of the will and the internal is not. The levator ani has a more complicated and in part an apparently inconsistent action, since it may pull the anus upward and probably dilate it, as it pulls its borders apart under the resistance of

the descending fæces, while at other times, by its antero-posterior fibres, it may compress the sides of the gut. To the action of the levator is probably due the control of the fæces which sometimes persists after division of the sphincter, unless, indeed, the upper part of the latter has escaped.

The Ischio-Rectal Fossa.—This space is a deep, roughly pyramidal hollow, filled chiefly with fat, on either side of the rectum. The base is at the skin between the tuberosity of the ischium and the anus, bounded in front by the line of reflection of the deep perineal fascia and behind by the great sacro-sciatic ligament and the edge of the gluteus maximus. The base measures some 5 cm. (2 in.) from before backward and half as much crosswise. The fossa is bounded externally by the tuberosity of the ischium and above the latter by the obturator fascia, internally by the external sphincter and the under surface of the levator ani. The space narrows above to a line at the splitting of the pelvic fascia; hence it can only vaguely be called pyramidal. The depth of the fossa is about 5 cm. (2 in.).

FIG. 1426.



Oblique transverse section through pelvis in plane shown in small outline figure.

The **diaphragmatic fascia**, the inward continuation of the pelvic fascia which covers the upper surface of the levator ani, reaches the side of the rectum as a bed of areolar tissue beneath the peritoneum, and is more or less closely attached to the gut, sometimes by muscular bands, as already stated. The systematic description of this fascia is given elsewhere (page 559).

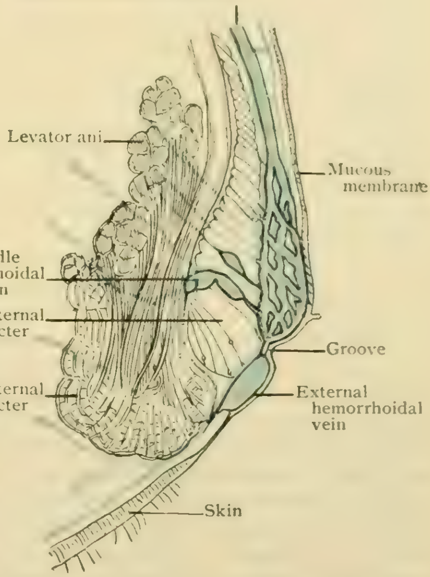
The **rectal fascia** is a dense layer of areolar tissue surrounding the rectum below the reflection of the peritoneum, being continuous below with the preceding fascia. It is particularly dense behind the rectum, which it separates from the sacrum and coccyx.

The **anal fascia** is a web-like areolar sheet covering the under side of the levator ani.

A **superficial fascia** between the skin and the base of the ischio-rectal fossa can be artificially dissected, but is of little importance.

Peritoneal Relations of the Rectum.—The posterior surface of the highest part of the rectum is usually coated like the rest with peritoneum, except near the median line; but this narrow retroperitoneal surface enlarges rapidly, so that soon the entire posterior surface in the hollow of the sacrum and coccyx is without serous covering. The gut rests on the dense rectal fascia. The sides and front of the rectum are covered with peritoneum, which is reflected laterally, first onto the sides of the posterior wall of the pelvis, then onto the floor. The peritoneum forms a deep pouch in front of the rectum, known from its anterior wall as the *recto-vesical* in the male and the *recto-uterine*, or the *pouch of Douglas*, in the female. In man this pouch separates the rectum from the bladder and the upper part of the seminal vesicles and in woman from the upper part of the vagina. The distance of the line of reflection of peritoneum—that is to say, the bottom of the pouch—from the ano-rectal groove may be as little as 5 cm. (2 in.), as usually given; if, however, by the word "anus" be understood what is practically the orifice of the gut, the distance is nearly 7 cm. ($2\frac{3}{4}$ in.) in both sexes. If both bladder and rectum be distended, the pouch is considerably raised; when the rectum is collapsed, it contains loops of the small intestine or the sigmoid flexure. The *recto-vesical folds* in the male, although described with the bladder (page 1905), should be mentioned here. They are reckoned among the false ligaments of the bladder, and bound laterally the pouch just described; extending backward from the bladder around the rectum to the sides of the sacrum, they tend to divide the cavity of the pelvis into an upper and a lower compartment. Their free edges are semilunar and sharp, and curve around the rectum above the ampulla, which they partially roof in. These ligaments contain more or less fibrous tissue. In the female they are less developed, although important, and, arising from the uterus instead of the bladder, are known as the *sacro-uterine* folds.

Fig. 1427.



Frontal section of wall of anal canal, showing relations of hemorrhoidal veins. (*Otis.*)

Blood-Vessels.—The *arteries* supplying the rectum are derived chiefly from the three hemorrhoidals. The superior hemorrhoidal, the termination of the inferior mesenteric artery, divides opposite the sacrum, sometimes near the beginning of the rectum, sometimes higher, and even above the pelvis, into two branches, of which the right is the larger, that descend on either side of the rectum and give off smaller branches. A median posterior branch usually arises from the right one. The mucous membrane is supplied by these above the boundary line. Vessels may be received also from the sacra media. The middle hemorrhoidal arteries, of uncertain origin and distribution, rarely give any considerable supply to the gut. The inferior hemorrhoidals—two or three small branches from the internal pudic—supply chiefly the external sphincter, but also form a number of fine anastomoses with the superior hemorrhoidal artery. The general distribution of the *veins* is not very different from that of the arteries. The superior hemorrhoidal veins, tributaries of the inferior mesenteric, drain into the portal system. They form a very rich plexus throughout the rectum, particularly in the upper and middle parts of the anal canal. In this situation they present a series of dilatations encircling the gut on the bases of the columns of Morgagni, just above the boundary line between the mucous and cutaneous areas; this line also marks the parting of the ways between the superior and external hemorrhoidal veins. The latter form

a circle of smaller dilatations just below the line of demarcation, in the region that is reckoned as skin, but is practically puckered into the anus. There are communications between the two systems, some of which pierce the muscular coat.

Lymphatics.—The principal lymphatics of the rectum, after joining the lymph-nodes situated along the superior hemorrhoidal veins, pass to the sacral glands on the front of the sacrum. In the lower part of the bowel a very rich plexus is found under the skin around the anus, which drains into the superior internal inguinal glands, and a still richer one inside, which at the lower part is concentrated on the columns of the rectum, but few vessels lying in the pouches. A considerable system of lymphatics exists also in the muscular layer. Most of those of the inside of the anus run to a few small lymph-nodules discovered by Gerota[1] on the back of the muscular coat of the rectum, distributed with the branches of the superior hemorrhoidal artery.

Nerves.—The nerve-supply of the rectum includes both sympathetic and cerebro-spinal fibres. The former are derived chiefly from the inferior mesenteric and the pelvic plexuses, accompanying the superior and middle hemorrhoidal arteries respectively. The cerebro-spinal fibres are contributed by the second, third, and fourth sacral nerves. The skin around the anal orifice is supplied by the inferior hemorrhoidal branch from the pudic nerve.

Growth.—At birth the rectum is tubular and generally relatively small. We do not remember to have seen a well-marked ampulla at that period. At least frequently the anal canal is very long,—about 1 cm. The transverse folds of the rectum are apparent in the latter months of pregnancy. We have found an ampulla with a circumference of 13 cm. (5 in.) at three years. In the same specimen the valves were well developed, and, except in size, it resembled the rectum of the adult. The peculiarities of the infantile sacrum have their effect on the course of the rectum, which is necessarily straighter than in the adult and does not run so far forward in front of the coccyx.

PRACTICAL CONSIDERATIONS: THE LARGE INTESTINE.

The Cæcum.—This part of the large intestine may remain undescended in its fœtal position in the left hypochondrium, at a point above and to the left of the umbilicus, the ileum opening directly into it in this locality; or it may be found in the right hypochondrium just below the liver, or at any level between that and its normal situation. The cæcum is rudimentary in man and other meat-eating animals, being much more capacious and of greater functional importance in the herbivora.

The cæcum is larger, more distensible, and more superficial than any other portion of the large intestine, and more mobile than any other portion except the sigmoid. On account of its mobility it is selected for the operation of iliac colostomy when that operation is done on the right side.

As a result of the inspissation of the intestinal contents, which first occurs here, it is a common seat of fecal impaction, or of distention by gases arising from fermentation. The increase in numbers of the intra-intestinal pathogenic bacteria due to impaired inhibiting power, which, as we descend the gut, first becomes marked in the lower ileum, continues in the cæcum. As in the former situation, where it probably aids in determining the localization of typhoid and tuberculous lesions, so in the cæcum, in conjunction with fecal accumulation, or with disturbance of circulation from distention, such augmentation adds to the frequency and severity of catarrhal inflammations and of stercoral ulcers, which are found oftener here than elsewhere.

Fecal concretions (the formation of which is favored by intestinal catarrh just as is that of renal calculi by catarrhal pyelitis) are often found in the cæcum, and undoubtedly by mechanical irritation favor here, as they do in the appendix, epithelial necrosis and subsequent infection.

In the erect position gravity aids in bringing about these pathological conditions, since the cæcum, having no mesentery of its own, and yet completely covered by peritoneum (so that it is never anchored to the posterior parietes or to the iliac fossa by areolar tissue), depends upon its attachments to the colon and ileum to hold

[1] Arch. für Anat. und Entwicklng., 1895.

it in position. It has often been part of the contents of right inguinal or femoral hernia, and has even been found in such herniæ on the left side.

The influence of gravity in retaining fecal masses and favoring concretion is illustrated by the fact that foreign bodies small enough to pass through the ileo-cæcal valve are prone to remain in the cæcum, where they have in many cases given rise to ulceration and perforation, followed by perityphlitis.

With varying degrees of displacement or of distention of the cæcum come changes in the tension of the ileo-colic vessels, and congestion—so often the first stage of serious pathological processes—is thereby favored. The close relation of the cæcum, if distended even slightly, to the anterior abdominal wall and to the ilio-psoas muscle exposes it to frequent trauma. These relations explain why flexion of the thigh on the abdomen will empty a moderately distended cæcum.

Enormous distention sometimes occurs, so that the cæcum may fill the larger part of the abdomen, and in nearly all cases of intestinal obstruction between the anus and the ascending colon the cæcum shows the most marked evidence of the backward pressure, the ileo-cæcal valve, although not absolutely complete, resisting, for a time at least, the participation of the ileum even in distention from gases. Manifestly, in uncomplicated cases of obstruction of the small intestine the cæcum will be found flaccid or collapsed.

The *ileo-cæcal valve* is usually competent to prevent the return of fecal matter from the cæcum into the ileum. Gas injected per rectum under pressure of from .7–1.02 kilos (1 ½–2 ¼ lbs.) (Senn) may be made to enter the ileum, and has been used in detecting and localizing wounds of the small intestine and in the treatment of intussusception. Less force is necessary when the patient is anæsthetized, probably because of the relaxation of both the abdominal muscles and the circular fibres of the valve itself. Fluids are arrested at the valve, although they may be made to pass it either by immediate force sufficient to lacerate the peritoneal attachments and covering or by slow increase of pressure until the distention of the cæcum gradually overcomes the weak resistance of the circular muscular fibres in the segments of the valve and separates their margins. Organic or spasmodic narrowing of the ileo-cæcal valve has been suggested as a possible cause of chronic constipation, and two cases have been operated upon by making a longitudinal incision through the valve and uniting its edges transversely, as in pyloroplasty (page 1633) (Mayo).

Invagination of the ileum and the cæcum into the colon is the most common form of intussusception (44 per cent. of all cases, Leichtenstern ; 89 cases out of 103, Wiggin), and occurs most commonly (70 per cent. of all cases) in children. The ileo-cæcal valve forms the summit or apex of the intussusceptum, and may pass through the entire colon (the intussuscipiens), reaching the rectum or anus. Ileo-colic intussusception—in which the ileum passes through the valve, the cæcum remaining in place—is much rarer (8 per cent. of all cases).

In acute cases, here as elsewhere in the intestinal tract, pressure on the mesentery produces consecutively venous congestion, œdema, swelling, obstruction or strangulation of the mesenteric vessels, and either leakage through the damaged intestinal walls and septic peritonitis or actual perforation, rupture, or gangrene of the bowel. In chronic cases dense adhesions form between the peritoneal coats of the entering and returning layers of gut (Fig. 1405). The traction upon the mesentery narrows the lumen of the intussusceptum so as to prevent the passage through it of the contents of the intestine.

In adults the *situation* of the ileo-cæcal valve corresponds to a point on the wall of the abdomen from 3–5 cm. (1–2 in.) internal to and above the anterior superior spine of the ilium.

The Vermiform Appendix.—On account of the frequency with which it is the seat of catarrhal or infectious disease, the appendix is of the greatest surgical interest. In addition to the description of its structure, position, and peritoneal relations already given (pages. 1664, 1665), various important anatomical data relating to the causes, symptoms, results or complications, and treatment of appendiceal inflammations should be here considered, even at the risk of repetition.

Etiology of Appendicitis.—1. The appendix is an apparently functionless organ, found only in man, in certain of the anthropoid apes, and in the wombat. An analo-

gous organ exists in some of the rodents and marsupials, but it is a long, tapering cæcum rather than an appendix strictly comparable to that of man. The appendix is a vestige of the capacious cæcum of some of the lower animals, or may be regarded as a rudimentary cæcum just as the human cæcum is a rudiment of that found in the herbivora or the rodents. Like other vestigial structures, or those which in the history of either the race or the individual have outlived their usefulness, it appears to be of low resistant power. This doubtless explains in part the special susceptibility of the appendix to disease, as it does that of the uterus and the female breast during the post-sexual period of life.

2. Its mesentery—a fold made by the passage of the appendicular artery from the ileo-colic at the back of the ileum to the appendix (page 1665)—is scanty; its free border is shorter than the border applied to the appendix, and sometimes does not extend much beyond its middle. The appendix, like the small intestine, is therefore thrown into irregular curves or coils. Another peritoneal duplicature—the ileo-cæcal fold—runs from that part of the ileum most remote from its mesenteric attachment and is united with the mesentery of the appendix. It carries no blood-vessels of consequence, and is regarded by Treves as the remains of the *true* mesentery of the appendix. It is interesting to note the fact that in the different types of the human cæcum those which involve a disproportionate growth of the cæcum show that it derives its peritoneal covering partly at the expense of the mesentery of the appendix, which becomes more scanty and more vertical in direction the larger the relative size of the cæcum. The appendix moves directly with the cæcum, but, through the attachments of the meso-appendix to the cæcum and to the mesentery of the ileum, distention or displacement of those portions of the intestine makes traction upon it and causes increased curving or angulation. For these reasons, and on account of the lessened interference with the blood-supply (*vide infra*), appendices with exceptionally ample mesenteries extending to the tip of the organ are less frequently the seat of disease and, when diseased, are less often found in a condition of complete gangrene.

3. The single artery supplying the appendix and running in the folds of the meso-appendix, and its accompanying veins, are subjected to pressure by such traction, or by the angulation of the organ itself, and various degrees of vascular obstruction and congestion may result. The consequent œdema and swelling of the mucous membrane aid the distortion of the appendix in causing interference with the escape of the contents of the appendix into the cæcum. After infection has started the vessels are not infrequently occluded by septic thrombi. The peritoneal fold, which in the female is often found running from the appendix to the broad ligament (page 1666), may contain a second artery the presence of which has been offered as an explanation of the relative infrequency of appendicitis in women.

4. The disproportion between the length and the lumen of the appendix (16 to 1, Finkelstein), the similar disproportion between the lumen and the area of the secreting surface, its removal from the direct intestinal current, the feebleness of its muscular walls, its dependent position, the absence or inefficiency of any valvular arrangement at the appendiculo-cæcal orifice, and the ease with which that orifice may be diminished in size by œdema of the mucous membrane in its vicinity readily explain the fact that under most circumstances in which drainage from the appendix into the intestine would be desirable, it is apt to be lacking. Even a hyperæmic catarrh from twists, kinks, or traction may in this way become the starting-point of serious trouble, the successive steps of which might subsequently be retention of mucus, epithelium, and fecal contents (possibly in the form of a concretion), ulceration, parietal infection, or perforation or gangrene, and peritonitis, localized or general.

5. The abundance of lymphoid tissue in the appendix, as in the tonsils, favors rapid swelling and infectious inflammations and aids in obstructing drainage. It may to some extent account for these pathological conditions showing themselves during the periods of growth and activity of the system much more frequently than in old age, when the lymph-nodules in the walls of the intestinal canal become atrophied (Struthers). In this connection it may be noted that other causes contributing to the relative frequency of appendicitis in early life are (*a*) the susceptibility of children

to catarrhal enteritis, favoring the formation of concretions, or at least impairing the protective power of the intestinal epithelium; (*b*) the relatively greater length of the appendix in young persons (in infants one-tenth and in adults one-twentieth the length of the large intestine, according to Ribbert) increasing the difficulty of drainage; and possibly (*c*) the tendency to shrinkage or obliteration after middle life,—a process to be expected in a rudimentary organ.

6. It must not be forgotten, in interpreting the foregoing anatomical facts as to (*a*) the rudimentary character of the appendix, (*b*) the scantiness of its mesentery, (*c*) its dependence for its blood-supply upon one vessel, (*d*) its imperfect drainage, and (*e*) the profusion of its lymphoid tissue, that these are but predisposing causes in most cases of serious appendix disease, and that the congestion, catarrh, distention, or ulceration occasioned by them occurs invariably in the presence of micro-organisms capable of great virulence, which exist in increased numbers in this portion of the intestinal tract (page 1680), and which, as has been abundantly proved, are ready to take on pathogenic action in the presence of either mechanical or chemical irritation of the intestinal tissues, especially if there is deficient drainage of the early products of such irritation or of the resultant inflammation. The proximity of the appendix to areas of abdominal or pelvic infection, as in typhoid fever, intestinal tuberculosis, dysentery, or salpingitis, is a factor of minor but definite importance.

Anatomical Points relating to the Symptoms of Appendicitis.—1. *Pain.*—This is at first general and diffused because the superior mesenteric plexus of the sympathetic, which supplies the appendix, also largely supplies the intestines, and because irritative nerve-pain is apt to be referred to the peripheral extremities of nerves; next and within a very short time felt in the umbilical region, because as such pain increases in intensity it is often referred to the nearest nerve-centre, and the great sympathetic ganglia of the abdomen are situated in proximity to that region.

At this time the pain is often colicky in nature, and a discussion has arisen as to whether or not the circular muscular fibres in the appendix are of sufficient strength to cause it. The question seems unimportant, as appendix irritation may result in colicky spasm of neighboring portions of either small or large intestine. The pain of the later stages of appendicitis may be partly due to peritoneal swelling causing traction upon the peritoneal attachments.

2. *Tenderness.*—After a few hours the pain is felt in the right iliac fossa, because it has then become a neuritis of sufficient grade to cause *tenderness on pressure.* It is *localized* tenderness in all the varieties of appendicitis, because, while the appendix itself is movable, it always arises from the same part of the cæcum, and the mobility of the latter is more restricted. The point of pain on pressure indicates, therefore, with moderate accuracy, the base, not the tip, of the appendix, and is rarely absent even in gangrenous cases, because that portion of the appendix is usually the last to be affected by interference with the blood-supply. This point is where the omphalo-spinous line (drawn from the umbilicus to the anterior superior iliac spine) meets the outer border of the rectus, or a point on that line from 5–7.5 cm. (2–3 in.) from the iliac spine (McBurney's point). In the majority of instances the base of the appendix lies beneath a circle two inches in diameter, having this point as its centre. Its situation must obviously vary with that of the cæcum and is not uncommonly lower, *i. e.* on the interspinous line. Undue diagnostic value has been placed upon tenderness at this precise position. The chief tenderness may be lumbar if the appendix is post-cæcal in position, or close to Poupart's ligament or to the median line, or best elicited by rectal touch if the appendix lies in the pelvis.

3. *Rigidity of the right rectus muscle*, and later of the other abdominal muscles over the right iliac fossa, is often, but perhaps not necessarily, due to peritonitis, and in any event arises from the fact that those muscles receive their nerve-supply partially from the six lower intercostals, while the superior mesenteric plexus gets its contribution from the spinal system through the splanchnics, derived from some of the same intercostals.

4. *Vomiting* commonly follows, has little relation to gastric conditions, is ordinarily reflex and due to reversed peristalsis, and is apt to be associated with moderate fever and slightly increased pulse-rate due to autotoxæmia.

Other and later symptoms are mentioned in the next section.

Results and Complications of Appendicitis.—A cursory review of the anatomical relations of the appendix, considered in conjunction with the pathological varieties of appendicitis, will explain the varying results of this disease. The appendix is entirely intraperitoneal in its situation and becomes primarily the focus of intraperitoneal lesions, although in certain cases (*vide infra*), from pathological changes, it and the associated exudate or abscess may be either practically or really extraperitoneal. That focus may be isolated by adhesions between the peritoneal coverings of the neighboring structures—the coils of small intestine, the cæcum or colon, the parietes —or may become the starting-point of a general septic peritonitis. In the former case the usual local symptoms of inflammation or of abscess will follow according to the behavior of the exudate, which may remain plastic or may liquefy and become purulent. In the latter case, to the above-mentioned symptoms—which are much intensified, as a rule—are added general rigidity from involvement of larger areas of the abdominal wall, distention and tympany from paresis of the small intestine (page 1756), and from the same cause obstinate vomiting and more or less complete intestinal obstruction.

The acuteness of the attack, the presence or absence of gross perforation or gangrene, and the anatomical position of the individual appendix will often determine the localization or diffusion of the septic infection.

The usual anatomical situations of appendix abscess may be summarized as follows. (1) *Anterior*, the cæcum forming the posterior wall, agglutinated coils of intestines the inner wall, and—after the abscess has attained some size—the parietal peritoneum the anterior wall. (2) *Posterior*, the hinder surface of the cæcum forming the anterior wall, especially if the appendix is post-cæcal in position, or if a septic lymphangitis has extended backward between the layers of the meso-appendix. Such an abscess is extraperitoneal, and may originate in an appendix which, it is believed by some, was *ab initio* either wholly or partly extraperitoneal (4 per cent., Bryant), or, as seems more probable, had become so through pathological causes (38 per cent., Ferguson, page 1666). The abscess is limited by the fascia transversalis anteriorly and the fascia iliaca posteriorly, and by their fusion at Poupart's ligament inferiorly, although rarely it may follow the femoral vessels downward and appear on the thigh, or may perforate the parietes above the outer third of Poupart's ligament, or may make its way into the peritoneal cavity, or into the pelvis, escaping through the obturator or the sacro-sciatic foramen. It may ascend (following sometimes the retro-colic fossa, page 1667) to the perinephric or even to the subphrenic region. (3) *Inner*, the inner surface of the colon and cæcum and the mesocolon bounding it postero-externally and adherent coils of small intestine antero-internally. If the parietal peritoneum does not form part of the anterior wall of such an abscess, the general peritoneal cavity must be traversed in reaching and evacuating it. (4) *Inferior*, the abscess occupying part of the pelvic cavity with agglutinated intestinal coils bounding it superiorly.

All these abscesses may perforate into the cavity of the peritoneum, but spontaneous opening into the cæcum, colon, rectum, small intestine, bladder, or on the surface of the body has frequently occurred (Finkelstein, quoted by Mynter). The various symptoms which may result from the propinquity of the abscess to other structures should be worked out anatomically,—*e.g.*, (1) *œdema* of the abdominal wall over the abscess; (2) *flexion of the thigh*, extension of which is painful from involvement of the ilio-psoas; or marked lumbar tenderness (perinephric); or immobility of the right lower thorax (subphrenic); (3) *tympany* over an ill-defined swelling, from interposition of coils of small intestine between the abscess and the parietes (although this may be simulated by the escape of intestinal gases through a gross perforation into the cavity of an abscess of any type); or (4) *vesical* or *rectal* irritation.

Anatomical Points relating to the Treatment of Appendicitis.—The medical treatment of this disease is of anatomical interest only in its relation to the possibility of removing the mechanical causes and favoring either resolution or localizing adhesions. Opium for the purpose of lessening peristalsis and thus permitting omental and intestinal adhesions to wall off the appendix has still some advocates, especially when combined with gastric lavage and exclusive rectal alimentation (Ochsner). But the received views as to etiology (*vide supra*) and clinical experience are both overwhelmingly in favor of purgation and starvation as preventing or removing the

constipation which, when involving the cæcum, may, by causing irritation and swelling of mucous membrane, by encouragement of bacterial growth, by favoring the formation of fecal concretions, by producing traction on the meso-appendix, or by direct pressure upon the appendicular vessels, start the chain of pathological phenomena which, beginning with hyperæmia, hypersecretion, and imperfect drainage, proceed to distention, ulceration, perforation, or gangrene, with their associated degrees of parietal or peritoneal infection.

Constipation is present in the majority of cases of appendicitis (58 out of 69, McCosh), and not only acts as a causative factor, but has a prejudicial effect on the result. In 22 cases of peritonitis from appendix disease occurring at the London Hospital there were 9 cases of constipation, with 4 deaths, and 13 cases in which the bowels were loose or easily moved, with 2 deaths. In another series of cases (Richardson) there was 8 per cent. of constipation among those that recovered and 28 per cent. among those that died (White). No other important point of medical treatment is in dispute and none has any anatomical bearing.

Operation for appendicitis will, of course, vary with the seat and character of the disease.

1. The preferable method of access in removal of an appendix very early in an attack, or during an interval, or when neither abscess nor extensive adhesions are present, is as follows. The incision begins one inch above a line drawn from the anterior superior spine to the umbilicus, and crosses that line one and a half inches internal to the iliac spine. It should pass downward and inward and be about three inches long. The skin and aponeurosis of the external oblique are divided in that direction; the internal oblique and transversalis fibres are separated in a direction almost at right angles to the first incision; the transversalis fascia and peritoneum are divided on the same line with the internal oblique.

The advantages of this incision are thus described by its originator. "Muscular and tendinous fibres are separated, but not divided, so that muscular action cannot tend to draw the edges of the wound apart, but rather to actively approximate them. Excepting during the incision of the skin, almost no bleeding occurs. The fascia transversalis not being drawn away by the retraction of the deepest layer of muscular fibres, this fascia is easily completely sutured, and thus greater strength of repair is assured" (McBurney).

More room may be obtained and the transverse severance of muscular or fascial fibres still minimized by stripping the external oblique aponeurosis up to the median line, dividing the anterior sheath of the rectus in the line of the separation of the internal oblique and transversalis fibres, lifting up and retracting the rectus towards the median line, ligating the epigastric vessels (which will be seen lying on the thin transversalis fascia over the peritoneum), and then extending the original peritoneal incision as far inward as may be necessary (Weir).

2. In later operations it is best to be guided by the situation of the tumor or the area of tenderness or dulness, inclining to approach it from without inward. An oblique incision well out towards the upper third of Poupart's ligament will be less likely to open the general peritoneal cavity unnecessarily in cases of abscess, and less likely to be followed by ventral hernia. In retroperitoneal abscess an incision so placed will not infrequently open the abscess without going through the peritoneum at all.

3. In the presence of general purulent peritonitis a vertical incision on the outer border of the rectus or a long median incision will best enable the appendix to be dealt with and at the same time permit of the efficient cleansing and irrigation of the peritoneal cavity and the introduction of drainage.

4. After the peritoneal opening is made the appendix can often easily be found and brought out of the wound. If this is not done readily, the colon should be identified—the first portion of intestine found attached to the posterior wall as the finger is passed along that wall inward from the incision—and the anterior muscular band traced downward to the base of the appendix.

The Colon and Sigmoid Flexure.—Like the other main subdivisions of the intestinal tract, the colon is larger at its commencement than at its termination, measuring on the average 8 cm. (3⅛ in.) in diameter at the cæcum and 3.5 cm.

(1⅜ in.) at the lower end of the sigmoid flexure. Its average capacity in infants of six months is ½ litre (1 pint); in children two years old, 1.25 litres (2.5 pints); and in adults, 4.5 litres (9 pints).

It is normally palpable through most of its extent, the more deeply placed hepatic and splenic flexures excepted, the former being beneath the liver, the latter behind the cardiac end of the stomach. The ascending and descending portions are usually overlapped in front by the more mobile small intestine, which, if not distended, can be displaced towards the median line. The thickened and sometimes tender edge of a chronically congested or inflamed cæcum can often be rolled under the finger against the floor of the iliac fossa, and has been mistaken for the appendix.

The colon is susceptible of great *distention*, and in cases of obstruction in the sigmoid flexure or rectum it may occupy most of the abdomen, push up the diaphragm, displace the heart, and occasion dyspnœa and palpitation.

Distention either from gas or fecal accumulation renders the colon visible, as well as palpable, except at the flexures. In chronic obstruction in the rectum or sigmoid its peristaltic movements may be seen through the thinned abdominal walls. In the common ileo-cæcal variety of intussusception the tumor can often be seen as well as felt, and sometimes the progress of the intussusceptum along the colon can be traced with the eye.

Tumors of the colon or upper end of the sigmoid are often visible in thin patients, especially when they have contracted anterior parietal attachments.

Distention of the colon gives rise to prominence and outward curving of the flanks, as the patient lies supine, and to fulness below the costal arches and the margin of the liver. The anterior surface of the belly—taking the umbilicus as a centre—is relatively flat. In distention of the small intestine the swelling is most marked in the latter region.

Normally the colonic percussion-note is of somewhat lower pitch than that of the small intestine, but of higher pitch than that of the stomach, the variation being due to the difference in the size of these viscera and in the thickness of their walls. In general gastro-intestinal distention the same variations are often observable.

A large quantity of fluid fæces in the colon will give rise to percussion dulness in the flanks, which may disappear when the patient is turned on his side. That sign is therefore not conclusive evidence of the presence of free fluid in the peritoneal cavity, unless the condition of the colon is known.

Rupture from distention—a rare occurrence—will usually be incomplete, the mucous membrane remaining unbroken.

Idiopathic dilatation of the colon has been seen in young children, chiefly among those affected with rickets.

Displacements.—The cæcum and ascending colon or the sigmoid and descending colon may be found in inguinal or femoral herniæ, may be at the median line of the body, or may even lie in the iliac fossa of the opposite side. A misplaced, movable, or enlarged kidney may cause variation in the position of the colon. "When the left kidney occupies the iliac fossa or is situated over the left sacro-iliac synchondrosis there is generally no sigmoid flexure in the left iliac fossa; but the descending colon passes across the middle line, and the rectum commences on the right side of the sacrum" (Morris). Paranephric tumors, by pressure on the colon, have produced such marked symptoms of intestinal obstruction as to be mistaken for intussusception (Ibid.).

The transverse colon, as the most movable of the three divisions of the colon proper, is peculiarly liable to assume abnormal positions, usually as a result of habitual constipation or secondary to obstruction lower in the gut. It can readily be understood how the weight of fecal masses may in time exaggerate the normal downward curve of the transverse colon, resting only on the easily displaced small intestine, and carry it towards the pubes, which it sometimes reaches. The normal level of the middle or lower portion of the transverse colon is at the upper umbilical or the lower epigastric region, or on the line separating those two regions. The position of the transverse colon in relation to the stomach varies greatly within normal limits. If the stomach is empty, it is behind the colon; if full or distended, it will push the latter downward and overlap it from in front.

The sigmoid flexure, the most movable part of the large intestine, normally occupies the pelvis rather than the iliac fossa (Fig. 1418), into which, however, it rises if displaced by pelvic swellings or by a distended bladder or rectum, or if it is itself distended.

From its shape and position and the relatively great length of its mesentery it is very liable to assume unusual positions. It may be found on the right side of the abdomen, may sink low in the pelvis (especially when loaded with fæces), and in this latter position may, as a result of ulceration, adhesion, and perforation, open into the bladder, the vagina, or even into the vas deferens (Allen), producing a fecal fistula.

Obstruction of the large intestine may be due to (1) *fecal impaction.* The presence of the sacculi, the inspissation of intestinal contents, and the necessity for overcoming gravity in the ascending colon, the left half of the transverse colon, and the lower segment of the sigmoid curve favor the production of this condition.

(2) *Stricture* is more common in the large intestine than in the small. It may be (*a*) *cicatricial* and follow dysenteric ulceration in the rectum, sigmoid, or descending colon; tuberculous or stercoral ulceration in the ileo-cæcal region; or syphilitic or tuberculous ulceration in the rectum; or (*b*) *malignant*, most common as we approach the termination of the intestinal tract, so that rectum, sigmoid, descending colon, hepatic flexure, splenic flexure, transverse colon, cæcum, and ascending colon represent the clinical order of frequency. The intimate relation of the hepatic flexure to the gall-bladder subjects it to various forms of irritation, which probably account for its relative susceptibility to malignant disease as compared with the transverse colon; while the mechanical conditions present in the cæcum (page 1680) apparently have a similar effect upon it, making it more frequently the seat of carcinoma than is the ascending colon.

Malignant disease, in addition to producing stricture and obstruction, may extend into and involve any of the neighboring viscera.

(3) *Volvulus*, in its usual form, is a twist of a portion of the bowel upon an axis passing transversely through the affected segment of gut and its mesentery. In more than two-thirds of all cases of volvulus the sigmoid loop is the part involved. The usual cause is habitual constipation. The gut, becoming paretic from continued distention, hangs over into the pelvis and drags upon and lengthens the mesosigmoid. Irregular contraction of the muscular layer of the gut in the effort to rid itself of the fecal mass, or accumulation of fæces in one segment of the loop, so that it falls over and descends below the other and less distended segment, may then cause the twist. The immediate result is stoppage of the fecal current from the pressure of the two ends of the loop on each other, and intense congestion of the whole loop from obstruction of the mesenteric vessels. Meteorism develops early and becomes excessive as the entire intestinal tract is sooner or later involved in the distention. Vomiting appears late and is not very marked. The difference in this respect between a volvulus of the sigmoid and an acute appendicitis (in which vomiting is often an early and significant symptom) may be due to the fact that the nerve-supply of the former is from the inferior mesenteric plexus, communicating directly with the aortic plexus and only indirectly with the solar plexus. The region of the cæcum and appendix, like the small intestine, is supplied by the superior mesenteric plexus, having relation especially and directly to the solar plexus and to the right pneumogastric. In volvulus of the small intestine vomiting is an early and persistent symptom. As well known, for mechanical reasons and because of the greater fluidity of the intestinal contents, vomiting is more apt to occur early and to be marked the higher the site of an intestinal obstruction.

The other forms of obstruction involving the large intestine—foreign bodies, bands, peritonitis, etc.—have no especial anatomical significance. Intussusception has already been mentioned. Hernia will be described later.

The *relations* of the large intestine should be carefully studied (Fig. 1383) in order to understand how (*a*) a renal, perinephric, or spinal abscess, or malignant neoplasm of the kidney may open into, obstruct, or involve either the ascending or descending colon; (*b*) a suppurating gall-bladder or an abscess of the liver may evacuate into the beginning of the transverse colon; (*c*) a gastro-colic fistula may become established in cases of gastric ulcer involving the greater curvature; (*d*) an aneurism

of the abdominal aorta may burst into the gut, the blood passing between the layers of the transverse mesocolon ; (*e*) an iliac abscess may discharge into the cæcum or sigmoid flexure ; (*f*) the latter may by ulceration communicate with the bladder or vagina ; (*g*) or may, in chronic fecal distention, produce left-sided varicocele (the more frequent) by pressure on the left spermatic vein.

The angulation at the junction of the lower end of the sigmoid flexure with the first part of the rectum, caused by the greater mobility of the former and its descent by gravitation to a lower level, often constitutes an obstacle to the passage of a bougie or tube, or sometimes even of liquids, into the sigmoid. In various examinations and in washing out the colon it is therefore frequently desirable to put the patient in the knee-chest posture, which often, by gravity, lessens or removes this cause of obstruction.

Usually a tube cannot be passed completely through the sigmoid flexure, but often carries the latter with it by engaging in a sacculus or a fold of mucous membrane. The tip of the instrument may be felt through the abdominal wall at a point at or beyond the mid-line, which may lead to the mistaken belief that it has entered the colon. Exceptionally it is possible to make it do so, the passage of the tube being facilitated by the injection through it, as it advances, of an oily liquid in sufficient quantity to distend as well as lubricate the sigmoid curve.

Wounds of the large intestine are less dangerous than those of any other portion of the intestinal tract because (*a*) the lessened fluidity of the intestinal contents diminishes the risk of fecal extravasation, and (*b*) if the wound passes through the lumbar parietes and involves only the posterior wall of the gut, the opening may be entirely extraperitoneal. According to Treves, a mesocolon is found in connection with the ascending colon approximately once in four times, and with the descending colon once in three and one-half times. In 75 cases out of 100, therefore, such a wound of the colon would be attended by a minimum of danger.

In *operations* on the large intestine it may be identified by (*a*) the longitudinal bands, especially the anterior and inner, the posterior being uncovered by peritoneum and therefore less conspicuous, and being placed along the attached border of the ascending and the descending colon ; (*b*) the epiploic appendages found more abundantly along the inner band and on the transverse colon ; (*c*) its sacculi which may be seen, and its fecal concretions which may often be felt ; and in addition, as compared with the small intestine, (*d*) its lesser mobility, greater diameter, and the absence of the palpable transverse ridges of the valvulæ conniventes. It should be remembered that when it is greatly distended the longitudinal bands and sacculi are almost or quite obliterated, and that the epiploic appendages—peritoneal pouches filled with fat—are absent on the posterior aspect of the gut and in the rectum.

Colostomy.—(*a*) *Lumbar.*—If the descending colon is opened through the loin, it should be through an incision following the oblique supra-iliac crease. The course of the gut corresponds to a vertical line 12 mm. (½ in.) external to the centre of the crest of the ilium. The incision crosses this at its middle, therefore a little below the kidney or on a level with its lower edge, and divides the posterior fibres of the external oblique, the anterior ones of the latissimus dorsi and those of the internal oblique, the lumbar fascia, the posterior fibres of the transversalis muscle, and the transversalis fascia. At this level the descending colon lies in the angle between the psoas and quadratus lumborum muscles. In the absence of a mesocolon (64 per cent.) the operation should be extraperitoneal.

(*b*) *Inguinal.*—An incision similar to that often employed in appendix cases and largely intermuscular may be made, its centre being 4 cm. (about 1½ in.) from the left anterior superior spine on a line from that point to the umbilicus. The sigmoid flexure, the portion of gut to be opened, may be recognized by the tæniæ, the sacculi, the appendages, etc.

The various operations to effect *anastomosis* between portions of intestine above and below occluded, diseased, or gangrenous areas depend for their success in many instances upon the mobility of the intestine and therefore upon the existence and the length of a mesocolon.

In *colectomy*, or complete resection of a portion of the large intestine, the usual care as to the vascular supply of the retained gut, the inversion of its edges, and the approximation of serous surfaces must be exercised.

The Rectum and Anus.—In relation to its diseases and injuries, the rectum may most conveniently be divided into two portions: (1) the *pelvic*, from the termination of the sigmoid flexure, at the middle of the third sacral vertebra, to the level of the reflection of the recto-vesical fascia from the upper surface of the levator ani to the wall of the rectum; and (2) the *perineal*,—the "anal canal,"—which extends from this level, through the floor of the pelvis, to the anus.

The recto-vesical fascia (page 1678), while perforated by vessels, constitutes an efficient barrier to the progress upward of infections or collections of pus and renders the surgical relations of the anal canal perineal instead of pelvic. The distinction between these portions is developmental as well as practical.

The pelvic portion is the termination of the hind-gut, which has a blind caudal end; the anal portion results from an inflection of the ectoblast. Between them lies the anal membrane, which may be persistent to a greater or less extent causing various degrees of constriction or resulting in *imperforate anus*. If thin, it is carried downward by the meconium, and may easily be felt and incised. If the septum is thicker and includes a layer of fibro-muscular tissue, a considerable distance may separate the lower end of the rectum and the rudimentary anal canal. Either portion may be completely absent.

The occasional abnormal opening of the rectum upon the surface of the body has been observed in the pubic, gluteal, lumbar, or sacral region. Its more frequent communication with the vagina, urethra, or bladder is explained by persistence of the early association of the gut-tube with the genital and urinary canals in the common cloacal space (page 1696).

In early childhood the pelvic portion of the rectum is straighter, more vertical, more of an abdominal organ, and more movable than later in life. The support given by the fascial reflections from the rectum to the other pelvic organs is less, on account of the undeveloped condition of the prostate and uterus. The sacral curve is less marked. The connective tissue between the mucous and muscular coats of the rectum, always lax, is especially so in children. *Prolapsus ani* is therefore not infrequent in them, especially when straining has been caused by the presence of lumbricoids or by other sources of rectal irritation. It occurs in adults, chiefly in old age, when muscular tonicity has been weakened, and is favored by chronic vesical or pulmonary conditions producing frequent straining or coughing. Between the normal protrusion from the anus during defecation of a very narrow ring of mucous membrane, which returns when the act is completed, and the extrusion of a large portion of the rectum (*procidentia recti*), including all its coats, every degree of prolapse may be met with. The anal canal is so firmly held by the levator ani that it is rarely involved in prolapse.

In many cases of prolapse the recto-vesical or recto-vaginal pouch is dragged down and is followed by coils of small intestine (which the pouch normally contains), so that it constitutes a hernial sac.

Hemorrhoids.—The anatomical conditions related to the development of varicosities or dilatations of the veins of the hemorrhoidal plexus may be summarized as follows: (1) The absence of valves and of any muscular or fascial support between the veins and the mucous membrane and the looseness of the submucous connective tissue rendering the effect of gravity in the sitting and standing postures particularly harmful. It should be noted in this connection that quadrupeds are almost free from this disease. (2) The passage of the tributaries of the superior hemorrhoidal vein directly through the muscular wall of the rectum, about three inches above the anus, causing intermittent constriction of the veins at that point. (3) The communication of the superior hemorrhoidal vein—carrying most of the blood—with the inferior mesenteric vein, and thus with the portal system, which is subject to periodic physiological congestions (as during digestion) and to frequent pathological obstruction. (4) The plexiform anastomoses just within the anus, between the inferior and middle and the superior hemorrhoidal tributaries (Fig. 767), so that the former, although connected with the systemic circulation, are subject to dilatation as a result of portal congestion. (5) The relation of the hemorrhoidal veins and of the terminal branches of the inferior mesenteric veins to the fecal contents of the sigmoid and rectum, exposing them to frequent pressure.

It may now readily be understood how, in the presence of the above predisposing conditions, hemorrhoids may result from (*a*) direct pressure upon the veins, as in constipation, pregnancy, ovarian or prostatic enlargements ; (*b*) indirect pressure through the column of blood, as in hepatic or splenic disease, or from the contraction of the diaphragm and abdominal muscles, as in coughing or lifting heavy weights, or as in straining due to the presence of stricture or vesical calculus or cystitis ; and (*c*) irritation of the rectum or anus, causing congestion of the hemorrhoidal veins.

It will be seen that chronic constipation is a possible cause of hemorrhoids under each of the above headings : the fecal masses press upon the veins, irritate the rectal mucosa, and necessitate straining for their expulsion.

Ulceration of the rectum and anal canal, whether from inflammation or infection following trauma (from indurated fæces or from foreign bodies), or caused by dysentery, tuberculosis, syphilis, or cancer, is of anatomical interest in its relation, first, to the vascular and nervous supply of the parts, and, next, to the surrounding regions.

The rectum proper is characterized, as Hilton long ago showed, by great distensibility and little sensibility ; the anal canal strongly resists distention and is extremely sensitive.

The rectum is supplied largely from the sympathetic system through the inferior mesenteric and hypogastric plexuses. The anal nerve-supply is chiefly from the sacral plexus, especially the fourth sacral and the pudic nerves, the filaments of which enter the gut at about the level of the "white line" which marks the junction of skin and mucous membrane and also the demarcation between the internal and external sphincters. The motor and sensory supply to the anal canal is far in excess of that to the rectum. Corresponding differences are observed in the vascular supply. Although the inferior mesenteric artery brings through the superior hemorrhoidal a relatively large amount of blood to the rectum, it contributes but little to the anal canal, which is richly vascularized by the pudic arteries.

These facts explain the extraordinary absence of subjective symptoms often observed in cases of large fecal accumulation, malignant growths, or extensive ulceration, when the rectum alone is involved. They likewise explain (through the association of the pudic, the fourth sacral, and other branches of the sacral plexus) the great pain of anal ulceration (*fissure*) or of inflamed and protruding hemorrhoids and the associated muscular cramps in the limbs, the vesical irritation or spasm (often causing post-operative retention of urine), the lumbar and iliac pains, and other reflex phenomena so common in anal disease.

The great power conferred upon the sphincters by their unusually rich nerve-supply, and developed by the resistance they must frequently and necessarily offer to the peristaltic action of the intestines and to the descent by gravity of feculent matter, enables these muscles, especially the external sphincter, through their obstinate and almost continuous reflex spasm, to become not only a cause of the excessive pain of fissure, but also an obstacle to healing. It is therefore usually requisite in the treatment of such ulcers to paralyze the sphincters by overstretching, often supplemented by either partial or complete section of the external sphincter. The higher an ulcer in the rectum the more amenable it is to treatment by physiological rest (Hilton).

Ulceration in the rectum, as elsewhere in the intestinal tract, may result in stricture, or in fistulous connection with neighboring organs or tracts, as the bladder or vagina.

Lymph infection proceeding from the rectum involves the pelvic and lumbar glands, especially those lying on the front of the sacrum ; if from the anal canal, the upper and inner inguinal glands are involved. The lymphatic distribution, like that of the nerves and blood-vessels, is thus seen to be quite different for the rectum and for the anal canal.

If infection spreads by vascular rather than lymphatic channels, it usually travels by way of the portal vessels and affects organs connected with the digestive system, especially the liver. Thus a not uncommon sequel of dysentery is hepatic abscess. On the other hand, emboli from external hemorrhoids have been known to enter the general venous circulation and have caused death.

Subcutaneous or submucous infection involving the anal canal may open into the canal (*incomplete internal fistula in ano*), or upon the cutaneous surface just without the margin of the anus (*incomplete external fistula in ano*), or in both directions (*complete fistula in ano*).

It may begin with ulceration within the canal (most often, but not necessarily, tuberculous), and may extend into the ischio-rectal fossa; or it may originate in that space, and, beginning as an *ischio-rectal abscess*, cause either of the above varieties of fistula. Such abscesses are very frequent because of (*a*) the proximity of the rectum, the frequency of rectal ulceration, and the invariably septic character of the rectal contents; (*b*) the poorly vascularized fat and loose connective tissue occupying the fossa; (*c*) the effect of gravity in inducing congestion; (*d*) the absence of muscles competent to facilitate the return of venous blood; (*e*) the slight but often repeated trauma caused by coughing or straining, the effect reaching the fossa through the impact of the intestines on the levator ani, its roof; (*f*) the exposure of its contents to frequent slight external trauma, as in sitting on irregular surfaces, and to marked changes of temperature.

The anal fascia, the levator ani, and the strong recto-vesical fascia offer usually a sufficient barrier to the progress of the abscess upward; its outward extension is limited by the obturator fascia, the obturator internus, and the tuberosity of the ischium (Fig. 1426). Internally, below the level of the levator ani, usually about 12 mm. (½ in.) above the anus, it finds its point of least resistance, and accordingly, when it results in fistula, the internal opening will usually be found about on the line between the sphincters, its higher exit from the fossa being prevented by the blending of the anal and recto-vesical fasciæ and the levator ani muscle with the bowel-wall. If it reaches the surface of the body, it will do so inferiorly in the space between the anus and the tuberosity of the ischium and the edge of the gluteus maximus behind and the reflection of the deep perineal fascia in front (Fig. 1423). This external opening is apt to be just beyond the outer margin of the external sphincter.

Such abscesses should be opened early on account of the suffering caused by pressure on the twigs of the small sciatic, the fourth sacral (on its way to supply the external sphincter), the inferior hemorrhoidal and superficial perineal nerves, and also to avoid the formation of fistula, and to forestall any possible extension upward and a resulting *pelvic cellulitis* from involvement of the connective tissue between the recto-vesical and pelvic fasciæ and the peritoneum (Fig. 1425). They should be opened widely to permit of perfect drainage, as the walls cannot definitely be approximated; the incision should be on a line radiating from the anus, so as to avoid the hemorrhoidal vessels. In the presence of fistula following such an abscess, the incision should unite the external and internal openings, and will usually divide the external sphincter and the wall of the rectum. Incontinence of fæces does not persist for any time, unless both sphincters are divided. The levator ani may aid in preventing it (page 1692).

In women free anterior division of the external sphincter may cause permanent incontinence on account of the laxness of its anterior connections, the interposition of the vagina preventing the firmer attachment to the pubes which in men is attained through the medium of the triangular ligament.

Fistula requires operation because drainage is imperfect and the region is acted upon by the contractions of the levator ani, the muscular coat of the gut itself, and by the external sphincter, the latter muscle being especially irritable and sometimes hypertrophied.

Cancer of the rectum may involve any portion, but is apt to be found within two or three inches of the anus. In addition to the symptoms of obstruction, the pain from contact of fæces with an ulcerated surface, and the blood which may streak the stools, there are symptoms due to its anatomical surroundings which should be carefully studied. If it extends towards the hollow of the sacrum, it will press upon the sacral plexus, causing pain which may suggest sciatica, lumbago, sacro-iliac disease, or coxalgia. If it extends anteriorly, distressing vesical symptoms in the male may distract attention from the real seat of the disease; while in the female menstrual derangement and suffering may have the same effect. Laterally it may involve the ischio-rectal fossæ, producing abscess and, later, multiple and intractable fistulæ.

If it spreads to distant parts, it should be remembered that, if it is high and follows lymphatic channels, it involves first the sacral glands in the sacral curve and then the lumbar glands by the sides of the lumbar vertebræ. The former, when much enlarged, may be felt with the finger in the rectum. The latter are palpable through the anterior abdominal wall. If the carcinoma is at or near the anus, the upper inguinal glands are apt to be first involved. If it spreads through the blood-vessels, it may, whatever its seat, follow the superior hemorrhoidal veins to the portal system and the liver or the internal pudic and iliac veins to the vena cava and to the lungs and elsewhere.

The *relations* of the rectum are of much practical importance. Those with the peritoneum have been described (page 1753). The fact that this membrane leaves the rectum uninvested posteriorly makes it possible in rectal cancer to remove safely more of the posterior than of the other walls. Penetrating ulcers are more apt to involve the peritoneal cavity if on the anterior wall.

In the male the rectum is in relation anteriorly to the prostate, the seminal vesicles, and the base of the bladder. Dilatation of the rectum raises the recto-vesical fold of peritoneum and elevates and advances the bladder, bringing a larger non-peritoneal surface in closer contact with the abdominal wall. This is sometimes made use of in suprapubic lithotomy or prostatectomy (*q.v.*). In the female rectal distention pushes the fundus uteri upward and towards the pubes.

Injuries to the rectum are dangerous, aside from shock and hemorrhage, on account of the risks of septic peritonitis or cellulitis. The height of the wound or rupture or perforation and its relation to the peritoneal pouch or to the recto-vesical fascia are of great importance. The rectum is less liable to direct trauma than are other portions of the intestinal tract, on account of the protection afforded it by the bony walls of the pelvis.

Enlargement of the prostate may so depress the anterior wall of the rectum as greatly to diminish its lumen. Occasionally symptoms of rectal obstruction are produced thereby. Acute prostatic inflammation and prostatic abscess may be recognized by rectal touch, as may similar conditions of the seminal vesicles. They are, for obvious reasons, apt to be associated with rectal irritation, tenesmus, and painful defecation.

In *operations* on the rectum, as for excision of carcinoma, it may be approached (*a*) from *below*, when the disease is near the anus, by isolating the lower end of the gut. If the anus is involved, the incision may be made outside the external sphincter; if not, the incision may follow the "white line." It will be necessary to divide the lateral fascial attachments, the levator ani on each side, the connective tissue between the rectum and vagina or rectum and urethra and prostate, and numerous hemorrhoidal branches. (*b*) It may be approached from *above*, when the growth is high, by opening the peritoneal cavity. The sigmoid may also be opened, the diseased segment of gut invaginated into it and excised, and the remainder of the rectum and sigmoid united (Maunsell). (*c*) It may be reached from in *front* through a median incision in the posterior wall of the vagina; or (*d*) from *behind* by removal of the coccyx; or, if more room is required, by detachment of the sacro-sciatic ligaments; or, in still more extensive disease, by resection (osteoplastic or otherwise) of the left half of the sacrum up to the level of the lower border of the third sacral foramen. Paralysis of the bladder may follow interference with the third sacral nerve. The sacral and coccygeal attachments on the left side of the levator ani, the coccygeus, and the sacro-sciatic ligaments must, of course, be divided, as must the fourth and fifth sacral and the coccygeal nerves. The lateral and median sacral arteries and their accompanying veins are raised, with the fibrous tissue on which they lie, from the anterior surface of the sacrum by a blunt elevator.

Examination per rectum may be made by the finger, by inspection, by bougies, or by the introduction of the whole hand.

(*a*) With the *finger* one can feel the involuntary contraction of the sphincters embracing the finger for the space of about an inch. If the patient is asked to contract the sphincter voluntarily, the levator ani will participate, as both muscles are innervated by the fourth sacral nerve. As a result of this, the upper margin of the contracted portion—*i.e.*, of the anal canal—will then be felt to "end abruptly and

give a sensation of a broad muscular band around the bowel" (Cripps). This is more distinct posteriorly and represents the posterior edge of the levator ani. It is from 1½–2 in. from the anus. A patulous condition of the anus or a cavernous or "ballooned" condition of the rectum should suggest stricture, the muscles below which, having no function to perform, become enlarged and yielding. An exceptionally tight grip of the finger, with marked tenderness, should suggest fissure.

If the patient is asked to strain, a slightly increased area of bowel will be made accessible to examination by the finger, but, except anteriorly, the finger cannot, as a rule, reach beyond the portions uncovered by peritoneum. The upward distance thus made palpable is on the average from 3–4 in. The distance from the anus to the recto-vesical pouch, when the bladder and rectum are empty, is about 2½ in.; when they are distended, it is about 3½ in. Growths in the sigmoid often descend so that they may be felt through the rectal wall with the finger.

Anteriorly, from 1½–2 in. from the anus, the prostate may be felt in the male. Between its apex and the anus the membranous urethra is accessible to digital examination and can be distinctly outlined when a catheter or sound occupies it. Posterior to the prostate there may be felt the triangular area of the base of the bladder, which is closely held to the rectum by dense connective tissue, and the sides of which are formed by the seminal vesicles, the base by the edge of the recto-vesical peritoneal pouch. It is through this triangle, and as near its apex—*i.e.*, the prostate—as possible, that the bladder is tapped per rectum, and it may be noted in connection with what has already been said as to the lack of sensibility in the upper rectum, that the operation—now rarely performed—is almost painless. The seminal vesicles, and in some cases a portion of the vas deferens, can be felt above the prostate and at the sides, especially if diseased. Their relations to the rectum explain the spurious cases of spermatorrhœa in which, during defecation, their contents are squeezed into the urethra by the descending fecal masses, exciting the apprehension of the patient, usually a young neurasthenic.

In children the bladder may be examined to its bas-fond, and, even if not distended, may be felt by bimanual palpation, one hand being above the pubes.

The back of the pubic bones and symphysis and the obturator foramina may also be reached anteriorly.

In females the recto-vaginal walls and the os uteri may be felt anteriorly and the broad ligaments and (in some cases of disease) the ovaries laterally. Laterally also, in both sexes, the inner aspect of the ischial tuberosities and part of the rami may be felt, as well as the inner walls of the ischio-rectal fossæ, which will be soft and yielding under normal conditions, and tense, tender, and bulging if an abscess occupies the ischio-rectal space.

The pulsations of some of the hemorrhoidal arteries may often be felt, and one or more of Houston's folds and the lower portion of the columns of Morgagni and the "valves" of the same name recognized. Posteriorly the front of the coccyx and the sacro-coccygeal junction can be reached.

(*b*) By *inspection*, with the aid of various specula, and with reflected or electric light, ulcers, polyps, or other new growths, the internal openings of fistulous tracts, hemorrhoids, fissure, and other pathological conditions may be seen. By placing the patient in the "knee-chest position" the intestines gravitate towards the diaphragm, the recto-vesical and recto-vaginal pouches are emptied, downward pressure upon the sigmoid and rectum is removed, the latter has room to dilate upon the admission of air, and inspection is thus facilitated.

(*c*) By *bougies* stricture may be recognized, but care must be taken that obstruction due to contact with one of the so-called "valves"—Houston's folds—is not mistaken for a contraction. It should be remembered, too, that the sigmoid is quite movable, and that the demonstration by touch of the presence of the end of the bougie close to the abdominal wall, even if it is also near the median line, does not prove that it has passed into the colon. It may have carried the sigmoid with it.

(*d*) By the *whole hand* introduced into the bowel there may be felt (in addition to the structures mentioned in *a*) (1) the spines of the ischium; (2) the curve and promontory of the sacrum; (3) the outlines of the greater and lesser sacro-ischiatic foramina; (4) the external iliac artery from the brim of the pelvis to the crural

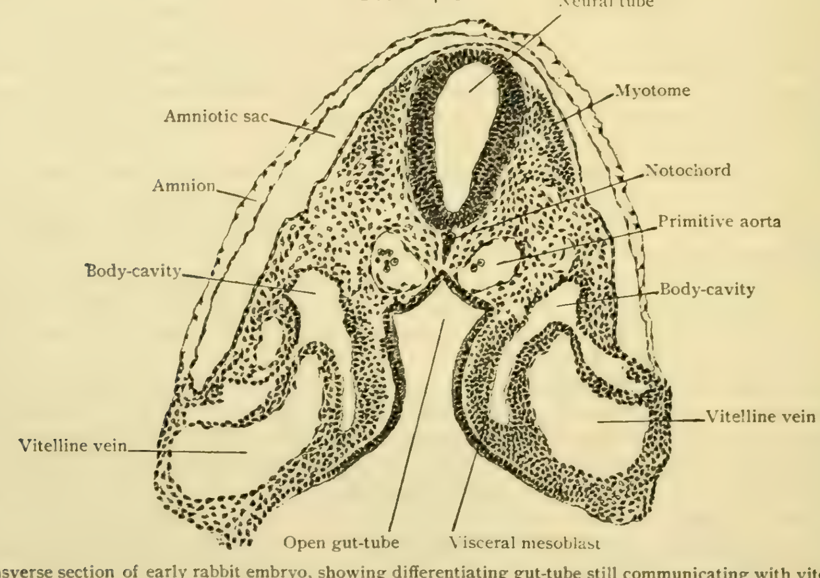
arch ; (5) the internal iliac artery through most of its course ; (6) in the female the uterus and the ovaries. If the hand will enter the sigmoid flexure, most of the abdomen may be explored.

Examination through the rectum by this method is distinctly dangerous from the risk of laceration of the gut. It is therefore not in much favor.

DEVELOPMENT OF THE ALIMENTARY TRACT.

Reference to the cross-section of a young mammalian embryo (Fig. 1428) shows the early relation between the primitive gut and the yolk-sac, of which latter the former is evidently a part. The longitudinal section of a very young human embryo (Fig. 46, page 39) emphasizes the wide communication between the two. The differentiation of the gut from the yolk-sac is accomplished by the approximation and union of the two splanchnopleuric folds which consist of the entoblast internally, continuous with that of the yolk-sac, and the visceral layer of the mesoblast externally. As the union of the splanchnopleuræ proceeds, the gut-tube becomes closed

FIG. 1428.



Transverse section of early rabbit embryo, showing differentiating gut-tube still communicating with vitelline sac. × 80.

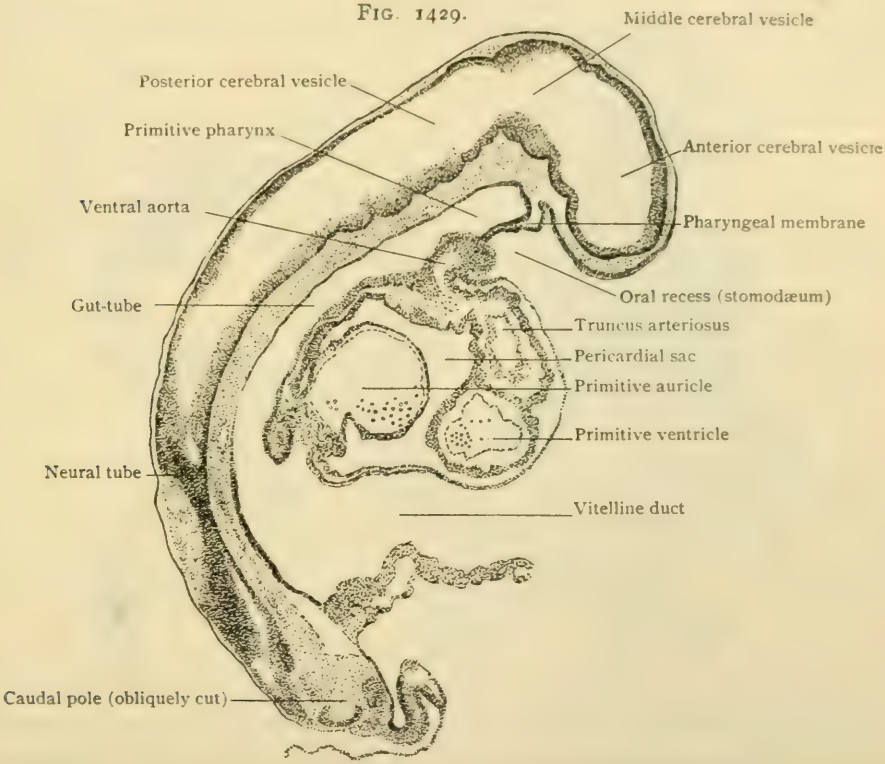
throughout its cephalic and caudal segments, between which, however, it remains open and connected with the yolk-sac by a communication that rapidly narrows and elongates into the vitelline or umbilical duct, a structure that for a considerable time remains as a canal bearing the diminishing yolk-sac or umbilical vesicle at its outer end. The primitive digestive tract, therefore, is closed both anteriorly and posteriorly, and soon may be divided into three segments : the *fore-*, *mid-*, and *hind-gut.*

Formation of the Mouth.—The cephalic segment, the fore-gut, is somewhat dilated at its anterior extremity, and there constitutes the *primitive pharynx*, which at first is separated from a bay-like depression, the *oral recess (stomodæum)*, which meanwhile has been formed by the downward flexure of the anterior cerebral vesicle and the development of the visceral arches. The septum between the fore-gut and the oral recess, the *pharyngeal membrane* (Fig. 1429), consists of the directly apposed entoblast lining the primitive pharynx and the ectoblast continued from the surface, no mesoblast intervening. The pharyngeal membrane very early (probably about the thirteenth or fourteenth day in man) becomes broken up by the formation of holes and soon disappears, the primitive oral and pharyngeal spaces thereafter freely communicating.

The entrance into the primary oral cavity is a pentagonal opening bounded by five projections,—superiorly by the unpaired *frontal process*, extending downward from the region of the anterior cerebral vesicle, laterally by the *maxillary processes*, and inferiorly by the fused *mandibular processes* of the first visceral arches (Fig. 74). The further changes leading to the formation of the definitive mouth and the separation of the oral and nasal cavities are described in connection with the development of body-form (page 59).

The primitive pharynx bears on each side a series of four lateral dilatations, the *pharyngeal pouches* (Fig. 73), corresponding to the inner half of the visceral clefts seen in water-breathing animals. In the mammals true fissures are not formed, the visceral clefts being represented by the external and internal furrows lying between the visceral arches and separated by a delicate ecto-entoblastic partition. The details of the development and metamorphosis of the visceral arches and furrows have been considered (page 60).

FIG. 1429.



Sagittal section of early rabbit embryo, showing oral recess and primitive pharynx still separated. × 12.

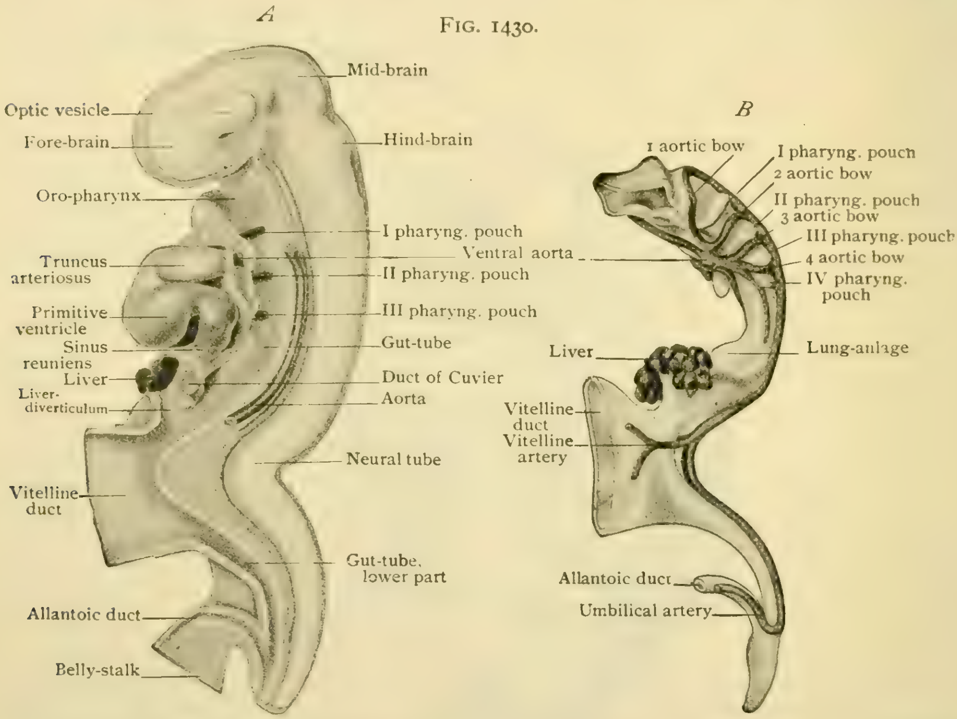
Formation of the Anus.—The posterior or caudal segment of the primitive gut-tube is the seat of the changes leading to the formation of the excretory orifice. Formerly the development of the anus was regarded largely as the repetition of a process similar to that leading to the communication between the oral recess and the fore-gut, an external depression (*proctodæum*) being separated from the hind-gut by an ecto-entoblastic partition which later was broken down to form the anus, which was considered a new structure.

The studies of Gasser, Kupffer, Bonnet, Hertwig, and others have emphasized the close relations between the anus and the blastopore. According to these investigations, the blastopore probably gives rise to the transient neurenteric canal, while behind the latter lies the rapidly proliferating tissue of the primitive streak. When the primitive streak is regarded as the fused and elongated blastopore (page 25), it follows that the anlage for the anus is located in the posterior part of that structure, and, further, that the primary position of the anal anlage is on the dorsal surface of the embryo.

Its migration to the ventral surface is associated with the growth and changes affecting the tract situated between the neurenteric canal and the anal anlage giving rise to the *tail-bud* (Hertwig) from which the caudal appendage arises. In consequence of the displacement occasioned by these changes, the anal anlage gradually assumes a ventral position immediately beneath the tail.

Coincident with this migration the primitive gut-tube becomes enlarged in the vicinity of the allantois to form a common space, the *cloaca*, into which open the hind gut, the allantois, the Wolffian ducts, and the caudal or *post-anal gut*, a temporary entension of the gut-tract toward the tail-bud. The ventral wall of the cloaca shutting it off from the exterior is formed by a delicate partition, the anal or *cloacal membrane* (Fig. 1644), consisting of the apposed entoblast and ectoblast. A slight depression, the *primitive anal groove*, indicates the position at which the membrane breaks through to establish the cloacal orifice in those forms, as birds and mono-

FIG. 1430.



Reconstruction of sagittally sectioned human embryo of third week, showing relations of digestive tube. × 26. (*After His model.*)

Reconstruction of digestive tube of preceding embryo; aortic bows and trunk also shown. × 26. (*After His model.*)

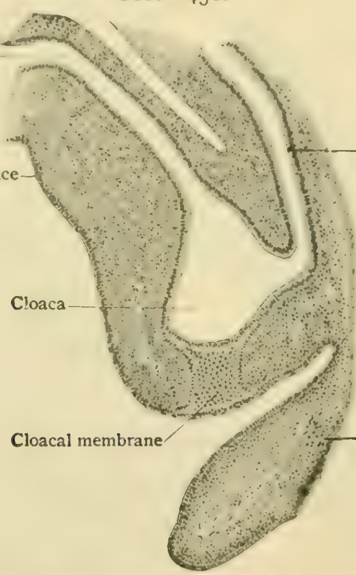
tremes, in which the cloaca persists. In the higher mammals the cloacal stage is only temporary, the cloaca becoming subdivided into two compartments by the formation of a septum, which grows downward to meet the cloacal membrane. The anterior compartment becomes the uro-genital sinus, the posterior the rectum. Later the remains of the cloacal membrane disappear, and these spaces are provided with the uro-genital cleft and the definitive anus respectively.

Differentiation of the simple gut-tube into distinctive segments begins with the stomach, which appears as a small spindle-form enlargement at some little distance below the primitive pharynx, the portion of the tube between the two corresponding to the early œsophagus. The gut-tube lies close to the posterior wall of the body-cavity, and at this stage (corresponding to about the fourth week in the human embryo) presents five divisions,—the primitive oral cavity, the primitive pharynx, the œsophagus, the stomach, and the intestinal tube, which latter freely communicates with the yolk-sac through the vitelline duct.

The digestive tube is at first closely bound to the posterior body-wall by a short, broad mesoblastic band. This attachment, or *primitive mesentery*, from the lower end of the œsophagus downward, gradually increases in its sagittal dimensions, at the expense of its breadth, in consequence of the gut-tube leaving the dorsal wall and assuming a more ventral position, the entire gastro-intestinal tube being thus attached by a mesentery. That portion of the latter connected with the stomach is known as the *mesogastrium*, that with the intestinal tube as the *mesenterium commune* (Fig. 1478).

The elongation of the stomach soon results in loss of the primary sagittal direction of its axis, which becomes oblique, the lower end of the organ passing to the right, while its upper end is displaced towards the left in consequence of the increasing volume of the liver. Embryos of the sixth week exhibit marked change in the form of the stomach, since the dorsal wall, later the greater curvature, has become bulged spineward, while the ventral surface presents a slight concavity foreshadowing the later smaller curvature. Somewhat later the stomach also undergoes rotation about its longitudinal axis, its primary left surface becoming the ventral or anterior, and its primary ventral border the lesser or upper curvature. The primary wall of the

FIG. 1431.



Part of caudal end of sagittal section of rabbit embryo of twelve days, showing cloacal space in communication with lower end of gut-tube and allantoic duct. × 35.

stomach consists of the entoblastic lining surrounded by the splanchnopleuric mesoblast. The differentiation of the gastric glands begins towards the close of the third month as minute epithelial outgrowths from the entoblastic layer. A few weeks later the glands become branched, and the parietal cells appear as differentiations from single epithelial elements lining the peptic follicles. In the fifth month the length of the glands has increased to about .20 mm., and during the succeeding month to from .40–.70 mm. (Kölliker). Differentiation of the mesoblastic tissue into the inner circular and outer muscular layers occurs during the fourth month.

The lower funnel-shaped pyloric end of the stomach at first passes insensibly into the relatively wide beginning of the characteristic U-shaped intestinal loop which extends from the stomach ventrally, its closed end or arch being attached to the vitelline duct, and then returns to the posterior body-wall to be continuous with the terminal segment, which maintains its sagittal relations in close attachment with the dorsal boundary of the body-cavity. The inferior limb of the loop early shows beginning differentiation into large intestine, the junction of the latter with the small intestine being indicated by the slight cæcal expansion. Even at this period a definite vascular relation has been established by the three main segments of the gastro-

intestinal tube and its mesentery. Within the mesogastrium course the three branches of the cœliac axis ; the superior mesenteric artery passes within the mesentery between the limbs of the intestinal loop, while the inferior mesenteric artery is distributed to the last part of the intestinal tube.

The subsequent changes which the intestinal tube exhibits during its growth have been carefully studied in reconstructions by Mall,[1] whose conclusions differ materially from the prevailing views. According to this investigator, the rapidly augmenting liver-mass occupies so large a portion of the still small abdominal cavity that there is no space left for the expansion of the intestinal tube. In consequence of this condition the greater part of the gut is early displaced from the abdominal cavity into the cœlom within the umbilical cord, the upper limb of the U-loop then lying to the right and the lower to the left. The growth of the small intestine—more rapid than that of the large—soon results in the production of six primary coils, the identity of which is retained not only throughout development, but can be established even in the adult (Mall). The first part of the gut-tube, continuous with the stomach and receiving the ducts of the liver and the pancreas, increases relatively little in its

FIG. 1432.

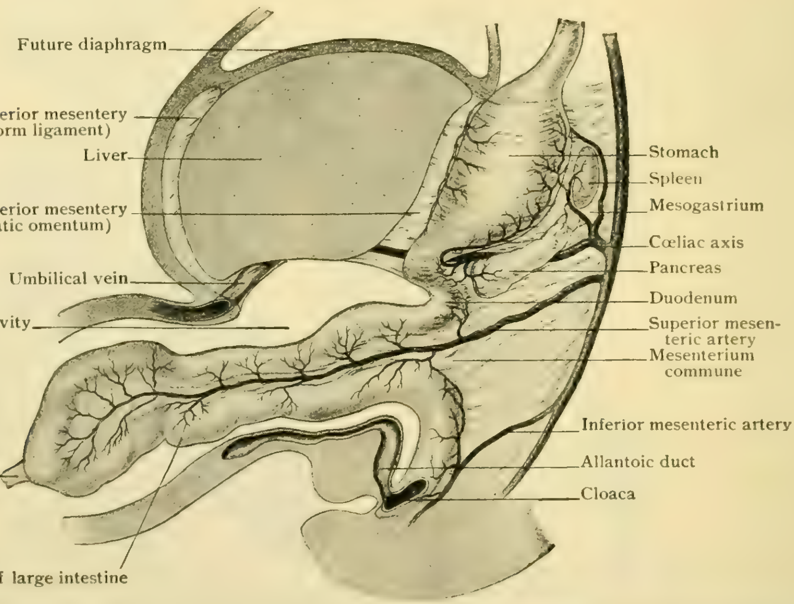


Diagram showing early relations of anterior and posterior mesentery. (*Based on figures of Mall and Toldt.*)

length, and therefore does not become secondarily convoluted, as do the remaining coils of the small intestine. This part is later represented by the duodenum. The other primary coils undergo great elongation, and consequently present secondary convolutions of increasing complexity, all of which for a considerable time (until the embryo has attained a length of about 30 mm.) are retained within the umbilical cœlom. About this period the lower part of the body grows rapidly, resulting in increased space within the peritoneal cavity, which now affords room for the temporarily displaced gut-coils. In consequence of these changes the intestine returns to the abdominal cavity, and in embryos of 40 mm. length the coils no longer lie within the umbilical cord. Mall has shown that their return to the abdominal cavity occurs in a definite order, the upper part of the small intestine being first withdrawn, the large intestine with its cæcal dilatation last. On re-entering the abdomen the upper part of the small gut passes to the left hypochondriac region, while the lower segment of the small intestine with the cæcum takes up a position towards the right hypochondriac region. Coincident with this migration the large intestine is differentiated

[1] Arch. für Anat. u. Physiol., Supplement Bd., 1897.

into a descending and a transverse colon, the former being the upper part of the vertical limb of the original dorsal flexure lying below the stomach. This flexure indicates the division between the descending and transverse colon, since the latter corresponds to the segment in front of the bend. Once back in the peritoneal cavity, the loops, which collectively lay in the sagittal plane of the cord, are arranged generally at right angles to the long axis of the body, and the antero-posterior colon becomes transverse (Mall[1]). In consequence of these changes the portion of the large gut that lay within the cord now lies obliquely across the abdomen in front of the duodenum, the remaining coils of the small intestine being placed below. The cæcum, therefore, occupies a position beneath the liver, on the right side, as a slight dilatation at the beginning of the transverse colon. The cæcum, while gradually increasing, retains this general position until adjustment in the length of the segments of the large intestine takes place shortly after birth. The lower part of the large gut is thrown into a loop extending across the abdominal cavity, which becomes the sigmoid flexure, the latter at birth including nearly one-half of the entire length of the colon. After the fourth month after birth, the sigmoid flexure becomes shorter and the other parts of the colon proportionately longer, in consequence of which the cæcum is pushed downward towards the right iliac fossa, with corresponding lengthening of the ascending colon. These portions of the large intestine, however, continue to grow for some time after birth, and it is not until the third year that they acquire their definitive relations.

FIG. 1433.

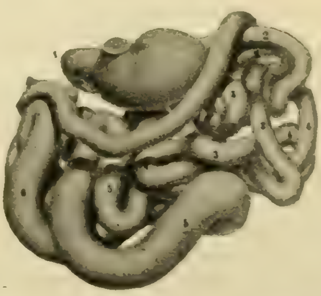
Reconstruction of intestinal tube and part of liver of human embryo of 17 mm. vertex-breech length. (Same embryo as represented in Fig. 1436.) *HV*, hepatic vein; *UV*, umbilical vein; *PV*, portal vein; *GB*, gall-bladder; *FW*, foramen of Winslow. The figures in this and in the two following reconstructions refer to corresponding parts of the gut-tube, 1 being gastro-duodenal junction. × 12. (*Mall.*)

The anomalous arrangement and position of the transverse and ascending colon and the cæcum, not infrequently observed in the adult, are usually dependent upon arrested development, the large intestine failing to take up a transverse and superior location, and hence altering its relations with the small intestine.

FIG. 1434.

Reconstruction of intestinal coils of human embryo of 28 mm. vertex-breech length. Arrow indicates position of foramen of Winslow. × 8. (*Mall.*)

FIG. 1435.



Reconstruction of intestinal coils of human embryo of 80 mm. vertex-breech length. × 2. (*Mall.*)

The cæcum, which first appears as a slight lateral diverticulum from the larger inferior limb of the primary U-loop of the gut-tube (Fig. 1432), increases in size until it forms a conical pouch, joining the colon where the latter receives the small intestine. The growth of all parts of the cæcum, however, is not uniform, since its

[1] Anatom. Anzeiger, Bd. xvi., 1899.

dependent terminal portion does not keep pace with that nearest the intestine. The apical segment of the cæcum remains proportionately small, and persists as the vermiform appendix. The latter, therefore, corresponds to the unexpanded morphological termination of the cæcum. This relation is evident at birth, when the appendix forms the direct continuation of the funnel-shaped cæcum; it is exceptionally retained in the adult as the fœtal type of cæcum occasionally observed. Usually the cæcum continues to expand with the colon, the demarcation of the appendix becoming progressively more emphasized, until the relative size of the two tubes commonly seen is established. The usual displacement of the appendix, so that it arises from the left and posterior wall of the cæcum, results from the later unequal expansion of the right side of the latter, whereby the origin of the appendix is pushed to the left.

Differentiation of the walls of the intestinal tube begins early in the third month by the formation of longitudinal folds, at first in the upper part, later the entire length of the small intestine. These folds increase in number and size, and subsequently break up transversely into areas from which the villi are formed. The latter first appear in the upper part of the small intestine in embryos of about 30 mm. in length (Berry[1]), and gradually extend to the lower segments, the villi being present throughout the small intestine in embryos of about 10 cm. in length. Villi also exist temporarily in the large intestine, but later undergo absorption, so that shortly after birth they have completely disappeared, while those within the small intestine have greatly increased in numbers and size. Early in the fourth month the intestinal glands appear in the upper part of the tube as minute diverticula clothed with extensions of the entoblastic lining of the gut. The glands of Brunner develop somewhat later during the same month as outgrowths of the entoblast. During the fourth month the mesoblastic stratum, from which arise all parts of the intestinal wall except the epithelial elements of the mucosa and the glands, undergoes differentiation into the muscular and areolar layers; by the close of the fifth month all coats of the intestine are well defined.

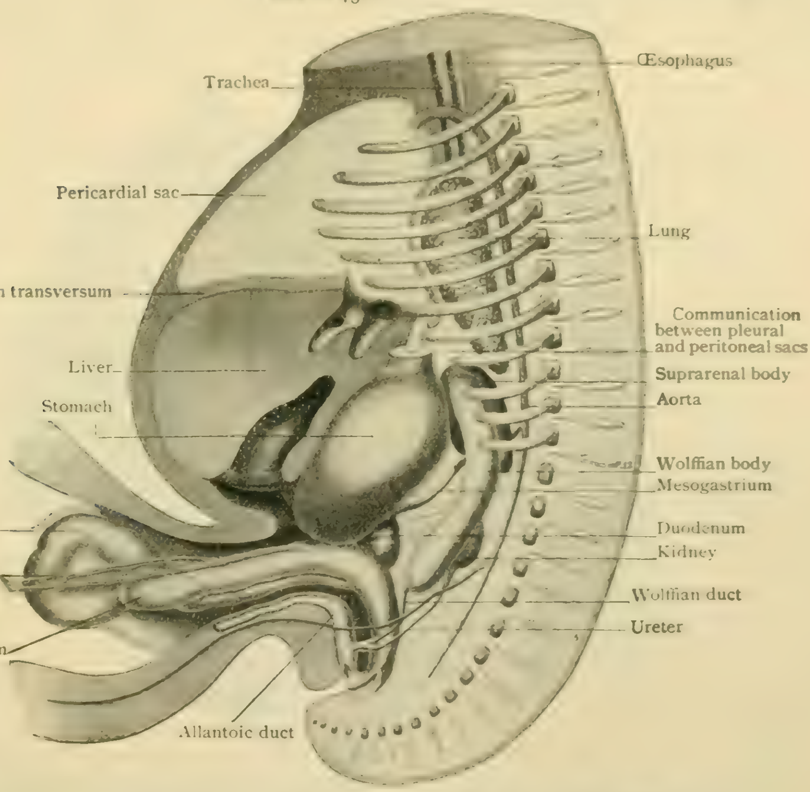
Differentiation of the Body-Cavity.—Owing to the precocious development of the mammalian heart, the latter organ is formed by the approximation and fusion of two lateral anlages, at first widely separated, in consequence of which union the upper part of the ventral body-wall is closed, while the more caudally situated is still incomplete, the gut-tube being but imperfectly separated from the yolk-sac. With the more advanced closure of the ventral body-wall the abdominal cavity is defined. The primary cœlom, according to His, may be divided, therefore, into an upper and a lower portion, the *parietal* and the *trunk-cavity* respectively. These spaces communicate on either side by an extension of the parietal cavity, the *parietal recess* of His. The ventral portion of the parietal cavity, which from its earliest appearance contains the heart, becomes the pericardial cavity, and is, therefore, appropriately named the *pericardial cœlom* (Mall[2]). The upper part of the parietal recess, since it later contains the lung and forms the greater portion of the surrounding lung-sac, may similarly be designated the *pleural cœlom*. For a time the separation between the pericardial and pleural cœloms is imperfect, owing to the incompleteness of the postero-lateral walls of the heart-sac. This deficiency is corrected by the growth and differentiation of the *pulmonary ridge* (Mall), a structure that extends from the liver along the dorsal wall of the duct of Cuvier to the dorsal attachment of the early fold suspending the heart, or mesocardium. Mall has shown that the pulmonary ridge grows headward as the *pleuro-pericardial membrane*, which completes the separation between the heart- and lung-sacs, and later tailward to form the *pleuro-peritoneal membrane*, which subsequently aids in closing the communication between the pleural and peritoneal cavities.

At first, immediately below the young heart lies the wall of the wide yolk-stalk, embedded within the mesoblastic tissue of which the two large vitelline veins pass in their course towards the lower end of the heart. With the formation of the body-wall and the narrowing of the yolk-stalk, the enlarged vitelline veins, in their journey towards the heart, produce a broad fold which projects horizontally into the body-

[1] Anatom. Anzeiger, Bd. xvii., 1900.
[2] Johns Hopkins Hospital Bulletin, vol. xii., 1901; Journal of Morphology, vol. xii., 1897.

cavity, and extends from the ventral wall to the sinus venosus, its median part beneath the heart being attached dorsally to the gut-tube, while its lateral expansions form the floor of the pleural cœlom. This imperfect partition, the *septum transversum* of His, also affords passage for the two ducts of Cuvier, formed on each side by the union of the primitive jugular and cardinal veins, to gain the sinus venosus; the septum transversum receives the hepatic outgrowth from the primitive duodenum, which soon develops a conspicuous liver-mass within the substance of the septum. The rapid increase in the mass of the developing liver is attended by great thickening of the septum transversum, particularly towards its dorsal edge. Coincidently with this augmentation, the septum differentiates into a thinner upper and a thicker lower stratum, the former constituting the floor of the pericardial cavity and surrounding the ducts of Cuvier, the latter enclosing the liver.

FIG. 1436.

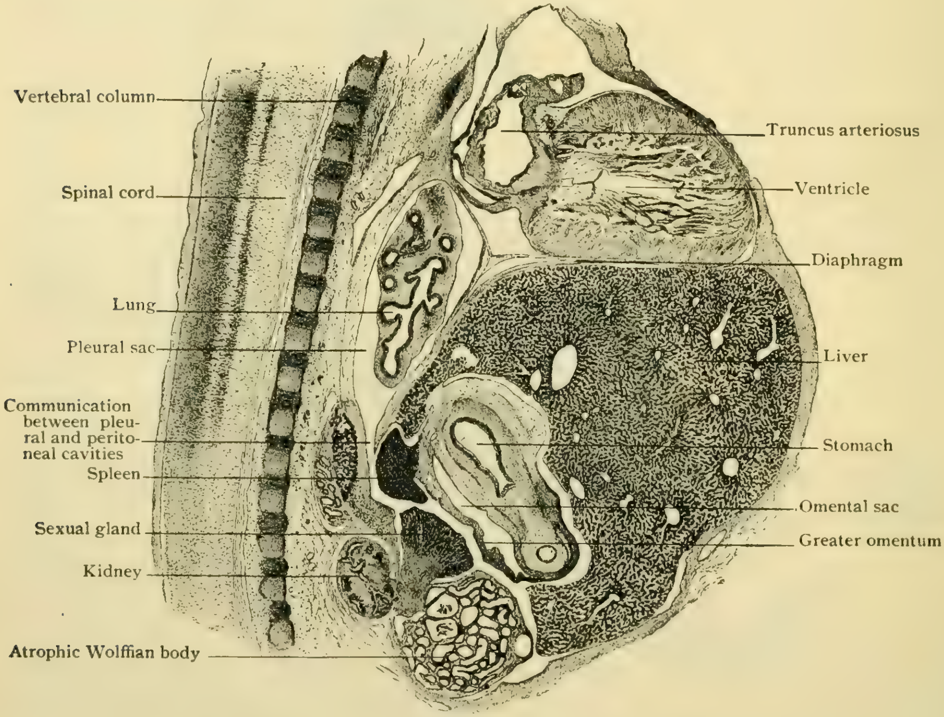


Reconstruction of human embryo of 17 mm. vertex-breech length. × 14. (*Mall.*)

The subsequent development of the liver is attended by progressive, although only partial, separation of the inferior layer from the superior stratum of the septum transversum, the latter layer remaining as the primitive, but still imperfect, diaphragm between the pleuro-pericardial and peritoneal divisions of the body-cavity. The dorsal attachment of the septum transversum, at first high in the cervical region, gradually recedes tailward. On reaching the level of the fourth cervical segment the fourth myotome is prolonged into the upper layer of the septum to supply muscular tissue to what now becomes the diaphragm. The latter, however, is still incomplete dorsally, owing to the existence on each side of the communication between the pulmonary and peritoneal sacs. This opening is gradually closed by the backward growth of the diaphragm and the forward and downward extension of the pleuro-peritoneal membrane until the aperture between the thoracic and abdominal cavities is effaced and the diaphragm is complete.

Development of the Peritoneum.—The attachment of the primitive alimentary tube, from the œsophagus downward, to the posterior wall of the body-cavity by means of a sagittal fold, the *primary mesentery*, has already been noted (page 1697). Likewise the conventional division of this duplicature into a lower part attached to the intestines, the *mesenterium commune*, and an upper portion passing to the dorsal surface of the stomach, the *mesogastrium*. The latter differs from the common mesentery in not ending at the ventral border of the digestive tube, but, after enclosing the stomach and the upper part of the duodenum, in continuing forward, embracing the liver, to be attached to the ventral body-wall. The portion of the duplicature between the stomach and duodenum and parietes is known as the *ventral mesogastrium*, or *anterior mesentery*, as distinguished from the dorsal mesogastrium behind the stomach. The ventral mesentery is at first attached above to the septum transversum and in front to the body-wall as far as the entrance of the umbilical vein, which occupies its lower free border as far as the liver. As already

FIG. 1437.



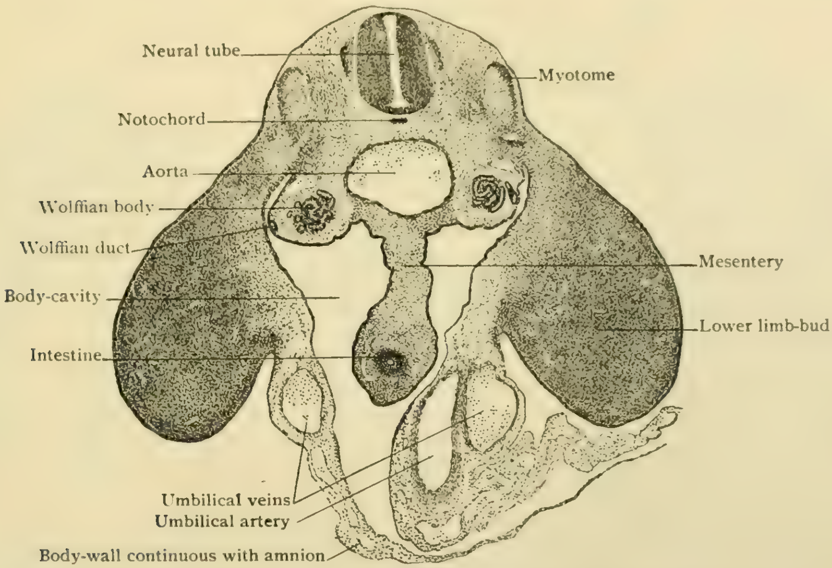
Part of sagittal section of pig embryo of 23 mm., showing thoracic and abdominal organs. × 15.

noted incidentally, the latter organ during its development is almost entirely freed from the diaphragm by the appearance of grooves on each side and before which cleave the septum transversum and almost completely separate the lower layer containing the liver, the lateral expansion of which organ materially aids in this process of delamination. The separation, however, is not complete, since the recesses over the sides and top of the liver do not quite meet in the mid-line, but leave a sagittal fold attached above to the diaphragm and below to the supero-ventral surface of the liver, beyond which it extends along the body-wall as far as the umbilicus. It is evident that this primitive, sickle-shaped fold foreshadows the persistent *falciform* or *suspensory ligament* of the adult organ, the lower free border of the duplicature enclosing the umbilical vein, later the ligamentum teres, in its passage to the under surface of the liver. The portion of the sagittal fold continued from the liver to the digestive tube later constitutes the *gastro-hepatic* or *lesser omentum* and contains the bile-duct, portal vein, and hepatic artery.

In general, the serous membranes lining the pleural and peritoneal cœloms represent the specialized mesoblastic layer forming the immediate boundary of these cavities. The peritoneum, therefore, covering the lower surface of the diaphragm and certain surfaces of the liver is derived from those portions of the septum transversum that constitute the upper and lower walls of the hepatic recesses which are instrumental in freeing the liver from its primary position within the septum. The separation of the liver from the diaphragm is incomplete not only above, as already noted, but also behind ; consequently the greater part of the posterior surface of the organ remains attached to the posterior body-wall by areolar tissue and is non-peritoneal, the remains of the peripheral portion of the lower layer of the septum transversum, which becomes the peritoneum of the liver, being reflected at the sides backward as the *coronary ligaments.*

Coincidently with the development of the liver and its liberation from the septum transversum, the stomach undergoes change in its axis, which becomes less vertical and more obliquely transverse, and in consequence its attachment to the liver, the primitive gastro-hepatic omentum, is drawn towards the right and assumes a

FIG. 1438.



Transverse section of rabbit embryo of eleven and a half days, showing primitive mesentery. × 35.

transverse position almost at right angles to its former sagittal plane. These alterations in the position of the stomach and its anterior mesentery affect the mesogastrium, which becomes elongated and twisted towards the right to follow the stomach in order to maintain its attachments to the greater curvature. The result of these changes is the production of a pocket behind the stomach, the floor and left wall of which are the mesogastrium, the roof being the under surface of the liver. This pocket, the *lesser sac of the peritoneum*, communicates with the remaining part of the peritoneal cavity on the right by means of a passage behind the displaced lesser or gastro-hepatic omentum, the free border of the latter bounding the opening leading into the passage or *vestibule* (page 1749). The opening, at first large, later diminishes in size and becomes the *foramen of Winslow*, which leads from the greater peritoneal sac into the vestibule of the lesser.

Beneath the stomach very soon appears an extension of the pocket, which pushes out between the stomach above and the transverse colon below. This protrusion, the *omental sac*, continues to grow downward and forms an apron which later, as the greater omentum, covers the loops of the small intestine. On referring to Fig. 1439, it is evident that the greater omentum at first comprises a duplicature the

anterior and the posterior fold of which each consists of two serous surfaces enclosing a thin stratum of intervening tissue ; there are, therefore, four serous layers included within the original omental curtain. Tracing the posterior fold of the latter upward, it is seen to pass over the transverse colon and the mesocolon, without attachment, to reach the posterior body-wall. On gaining the latter, the anterior or inner serous layer may be followed in front of the pancreas as the posterior wall of the lesser peritoneal sac, being continued over the under surface of the liver. The outer or posterior serous layer passes behind the pancreas to reach the body-wall, from which it is reflected to become continuous with the upper layer of the transverse mesocolon. For a time these original fœtal relations persist, the greater omentum being unattached to and removable from the transverse colon and its mesentery. Later this separation is no longer possible, since the posterior layer of the greater omentum and the transverse mesocolon and colon become fused, the intervening serous surfaces and space being obliterated in consequence. Thereafter the peritoneal layers of the greater omentum are attached to and apparently enclose the large gut, one passing as the upper, the other as the lower serous layer of the transverse mesocolon. In consequence of these fusions the serous surfaces originally behind the pancreas also disappear, and the gland thenceforth assumes its permanent, although secondary, retroperitoneal relation. Subsequently the originally distinct folds constituting the greater omentum fuse, and after birth usually appear as a single sheet attached above to the greater curvature of the stomach and behind and below to the transverse colon.

The excessive volume of the right half of the liver not only induces the obliquity and rotation of the stomach, but likewise influences the disposition of the intestinal coils on their return from the umbilical cœlom into the peritoneal cavity. The duodenal segment necessarily follows the migration of the pylorus ; its beginning, therefore, lies to the right, while the lower end passes to the left with the jejunum. Since the most available space within the abdomen, to the left and below, is appropriated by the coils of the small intestine which first return to the peritoneal cavity, the most movable portion of the elongating large intestine, the transverse colon, is displaced upward and assumes an obliquely transverse position beneath the stomach and liver, above the rapidly increasing volume of the coils of the small gut. The latter tend to displace the descending, later also the ascending, colon laterally and backward. In consequence of these influences and changes the transverse colon crosses and lies in front of the duodenum, which is thus pushed against the abdominal wall. The serous investment of the duodenum undergoes obliteration where such contact is maintained, and later occurs chiefly on the anterior surface of this part of the gut (Fig. 1403).

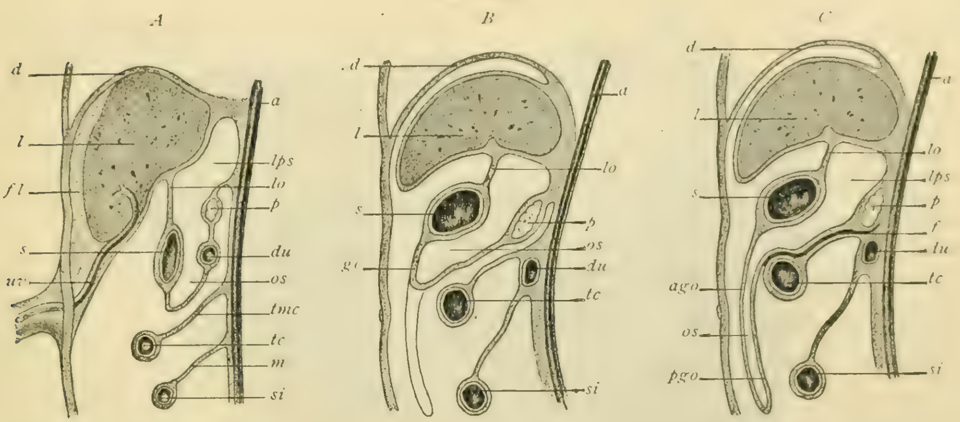
Reference to the original relation of the primitive mesentery (Fig. 1432) included between the limits of the U-loop shows the principal dorsal attachment of the mesentery to be the comparatively limited area along the body-wall opposite the umbilical loop. The intestinal margin of the mesentery, on the contrary, rapidly expands to keep pace with the increasing length of the gut-coils, the result being that the mesentery attached to the upper—soon right—limb of the umbilical loop assumes more and more the form of a ruffle, towards the edge of which ramify the branches of the superior mesenteric artery supplying the small intestine,—the later vasa intestini tenuis. The branches distributed to the left or colic limb of the U-loop pass to the large gut through a mesentery only slightly wavy. When the arrangement of the intestinal coils takes place, the small gut occupying the left and lower parts of the peritoneal cavity and the large intestine being reflected upward and across the duodenum, twisting or "rotation" takes place around a fixed point marking the duodeno-jejunal junction. This location also corresponds in general to the early position of the superior mesenteric artery, the relations of the branches of which are also affected by the rotation of the mesentery, since thereafter the vessels passing to the coils of the small intestine lie on the left and those to the large gut on the right side,—the opposite of their original situation.

On assuming its position in front of the duodenum, the attachment of the transverse colon is at first a limited sagittal one. With the backward displacement of the duodenum, the mesentery of the transverse colon also comes into relation with the posterior parietal peritoneum and acquires a secondary attachment extending cross-

wise, thus forming the dorsal connections of the transverse mesocolon which exist until fusion takes place between this duplicature and the posterior fold of the omental sac. Since originally all parts of the large gut possess a mesentery, the descending colon and sigmoid are for a time provided with a free mesocolon. In consequence of the increasing bulk of the small intestine the descending colon is pushed not only to the left, but also against the body-wall. The intervening serous surfaces usually disappear behind the gut, which later, therefore, ordinarily possesses a peritoneal coat only in front and at the sides. In a considerable number of cases, however, this fusion and obliteration do not take place, the mesocolon, although displaced towards the left, then persisting as a free mesentery for this segment of the gut. The fold attached to the sigmoid for a time allows of great mobility; subsequently this is reduced, although partly retained as the definite mesosigmoid. The rectal segment of the large gut retains its primary sagittal situation, but loses the greater part of its peritoneal coat, becoming attached to the posterior pelvic wall by areolar tissue.

The ascending colon and cæcum, in their downward growth towards the right iliac fossa from the hepatic flexure, carry with them a peritoneal covering. This remains

FIG. 1439.



Diagrams illustrating formation of greater omentum and omental sac. *A* shows duodenum and pancreas in mesogastrium unattached; in *B* these organs are partly against posterior abdominal wall, posterior wall of lesser peritoneal cavity is still free; in *C* duodenum and pancreas lie against posterior abdominal wall, posterior wall of omental sac has fused with transverse mesocolon. *a*, aorta; *d*, diaphragm; *l*, liver; *fl*, falciform ligament; *uv*, umbilical vein; *s*, stomach; *tc*, transverse colon attached by transverse mesocolon (*tmc*); *si*, small intestine attached by mesentery (*m*); *p*, pancreas; *du*, duodenum; *lps*, lesser peritoneal sac; *os*, omental sac; *lo*, lesser omentum; *go*, greater omentum; *ago* and *pgo*, its anterior and posterior layers; *f*, fusion between posterior wall of lesser peritoneal sac and transverse mesocolon. (*After Kollmann and Hertwig.*)

unattached over the cæcum and appendix, but forms secondary connections where the ascending colon comes into contact with the abdominal wall; hence this part of the colon usually possesses a serous coat only anteriorly and laterally. Sometimes, however, obliteration of the serous covering does not take place, the ascending colon being attached by a mesocolon.

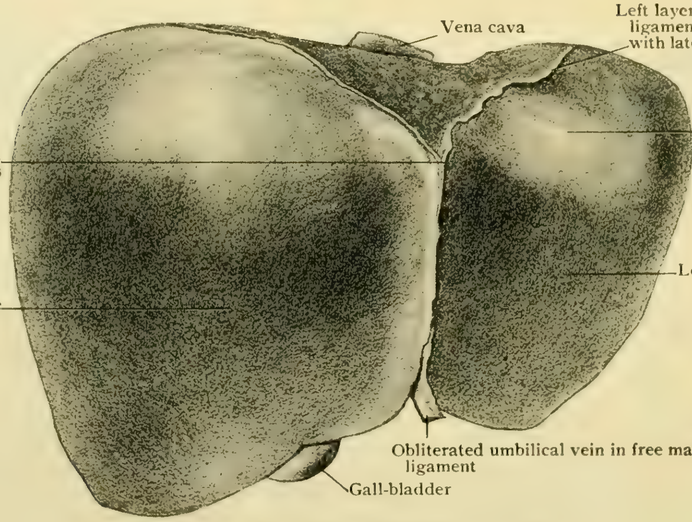
The vermiform appendix being primarily an outgrowth from the large gut, since it represents the morphological apex of the cæcum, is completely invested with peritoneum and is without a mesentery. Later the appendicular artery, in its course from the ileo-colic to the appendix, produces a serous fold which stretches from the left layer of the mesentery of the ileum to the cæcum and appendix. This fold, the meso-appendix, is, therefore, functionally, but not morphologically, a true mesentery.

THE LIVER.

The liver (**hepar**), the largest gland in the body, is formed of very delicate tissue disposed around the ramifications of the portal vein. It is developed in the anterior mesentery, its mesoblastic elements having a common origin with the diaphragm,

while its duct and glandular elements are derived from a sprout from the duodenum ; hence the liver, as are other glands connected with the digestive tract, is an outgrowth and appendage of the alimentary tube. Its peculiar shape is chiefly due to the pressure of surrounding organs, as its tissue is so plastic that it is moulded by them. In the adult it becomes firmer from the increase of connective tissue, but under normal circumstances it is always very soft, and, unless hardening agents are used before its removal, collapses into a flattened cake-like mass affording little information as to its true form. Indeed, it is only in the present generation, since the introduction of adequate methods of hardening *in situ*, that this has been learned. The liver in general may be described as an ovoid mass which in the young fœtus nearly fills the abdomen, but in the adult has the appearance of having had at least a third of its substance scooped out from below, the back having been left intact at the right end only. The organ is therefore a thick mass in the right hypochondrium, growing thinner to the left. The greatest diameter is transverse and the next vertical. The liver is usually described as composed of five lobes,—namely, the *right*, the *left*, the *lobe of Spigelius*, the *quadrate*, and the *caudate*. More properly it consists of a right and a left lobe, separated on the superior surface by the falciform ligament. The other lobes are subdivisions of the right lobe, the lobe

FIG. 1440.



Antero-superior surface of liver hardened *in situ*.

of Spigelius being at the back and the other two below. They are described with the respective surfaces. The **size** varies greatly with the size of the body and from many other causes. The transverse diameter usually nearly equals that of the cavity of the abdomen, although it often falls an inch or so short of it. It may be given at from 22–24 cm. (8½–9½ in.). The greatest vertical dimension or depth is about 16 cm. (6¼ in.); the antero-posterior diameter 12–18.5 cm. (4¾–7¼ in.). One peculiar form of liver occasionally met with shows great increase of the right lobe, particularly in the vertical direction, with a want of development of the left lobe, which is thin and short (Fig. 1456). The **weight** is, with considerable variations, generally from 1450–1750 gm., or approximately from 3–3¾ lbs., and in the adult is about one-fortieth of the body weight. The specific gravity is given at from 1005–1006. The color is a reddish brown. The naked eye can recognize that the surface is covered with the outlines of polygons from 1–2 mm. in diameter. These are the *lobules*, each of which is surrounded by vessels and ducts in connective tissue, and contains in the middle a vessel, the beginning of the system of the hepatic vein. Sometimes the centre of the lobule is lighter than the periphery, sometimes the reverse, depending upon whether the blood has stagnated in the portal or hepatic system respectively.

Surfaces.—In its natural form, as shown in specimens hardened before removal from the body, the liver presents five surfaces. The *superior surface* is in the main convex, looking upward beneath the diaphragm. The *anterior surface*, directed forward, is continuous with the former, on the hardened liver a fairly distinct line marking the change of direction that separates them. The *right surface* faces towards the right and is separated in a similar way from the superior. It passes insensibly into the anterior surface. In a flaccid liver, in which the normal form has been lost, these three surfaces are indistinguishable, constituting the old superior surface. In the hardened organ the three represent a dome, of which the flattened upper surface is slightly separated from the others. The *posterior surface* is on the back of the right lobe. The *inferior surface* is moulded over the organs beneath it.

The **borders** are best described from the posterior surface as a starting-point. The upper border of the latter separates it from the superior and right surfaces; the lower border from the inferior. On the right these meet at a more or less acute angle. On the left the posterior surface narrows to a border, first thick and then sharp, which runs around the liver, separating first the upper and lower surfaces of the left lobe and later the lower from the anterior and right ones, until finally it reaches the right end of the lower border of the posterior surface. Along the front of the liver the border is sharp and directed downward, overhanging the concave lower surface. A conspicuous incision, the *umbilical notch* (**incisura umbilicalis**), in the anterior border marks the place at which a sickle-like fold of peritoneum, the *falciform ligament*, conveying the obliterated umbilical vein, now the *round ligament* (**ligamentum teres hepatis**), to the lower surface, reaches the liver. The falciform ligament is continued back between the top of the liver and the diaphragm, and marks off on the anterior and superior surfaces a large *right lobe* and a small *left* one.

The **superior surface** (Fig. 1440) includes the upper part of both lobes and is moulded to the opposed surface of the diaphragm. The top of the right lobe fills in the whole of the space below the corresponding half of the diaphragm, but the left lobe does not usually reach the walls of the abdomen, unless in front. It may, however, touch the left wall. Well-hardened livers show a slight *cardiac depression* on the left lobe beneath the heart. The posterior border of the superior surface is marked on the right lobe by the reflection of the peritoneum onto the diaphragm above the triangular posterior surface, and on the left by the rounded posterior border of the liver.

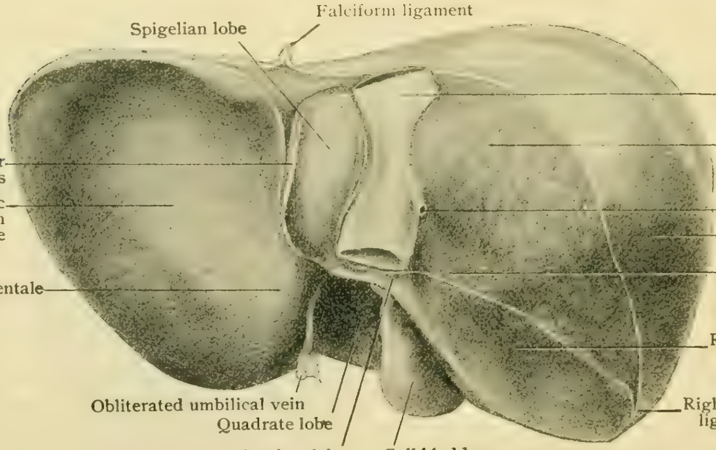
The **right** and **anterior surfaces** lie against the diaphragm, except where the anterior rests against the abdominal wall between the costal arches, and offer little for description.

The **posterior surface** (Figs. 1441, 1456), on the back of the right lobe, consists of a triangular *non-peritoneal area* and of the *lobe of Spigelius*. The former, adherent to the diaphragm, extends from the inferior vena cava to the right, where it ends in the point formed by the meeting of the upper and lower borders. The greatest vertical dimension of the non-peritoneal area is not over 7.5 cm. (3 in.), and the transverse not over 12.5 cm. (5 in.). A triangular hollow at the lower border of this space, just to the right of the vena cava, receives the right *suprarenal capsule*, which rests also on the lower surface. To the left of this depression is a deep furrow for the *inferior vena cava*, which sometimes at the top is converted into a canal. Still farther to the left is the **lobe of Spigelius** (**lobus caudatus**),—a four-sided prism placed vertically on the back of the liver, bounding a part of the lesser cavity of the peritoneum. The lower end, which hangs free, is continuous on the right with the caudate lobe (**processus caudatus**). It often presents on the left of the lower end a distinct tubercle, the *tuber papillare* (His), which is by no means constant. The Spigelian lobe lies between the fossa of the vena cava on the right and the *fissure of the ductus venosus* on the left. The latter joins the former in front of this lobe, just below the diaphragm, so that the lobe ends in a point above. It more or less encircles the vena cava, sometimes meeting the right lobe behind it. The vena cava is frequently overlapped by a projection from the right lobe, and sometimes the overlapping is done both by this and by the lobe of Spigelius. The prismatic shape of the latter is well shown by transverse sections. The amount of attachment to the rest of the liver varies, and the shape of the lobe with it. Sometimes the fissure of the ductus

venosus makes but a small angle with the portal fissure, so that it is a three- instead of a four-sided prism. It is also influenced by the depth of the fossa for the vena cava, at times being attached merely by a line of tissue. To the left of the fissure of the ductus venosus the posterior surface of the liver is continued as the posterior border. This at first is thick, and presents a rounded *œsophageal impression* for the end of the gullet to the left of which it becomes sharp.

The **inferior surface** (Fig. 1442) of the liver is subdivided by a system of fissures formerly described as resembling an H. This description must be modified by recognizing that the posterior limbs of the H are not horizontal, but run vertically on the hind surface of the liver, and that the cross-piece—the portal fissure—is not in the middle, but very near the posterior border of the inferior surface. The old error came from studying distorted livers in which the posterior surface had flattened out so as to be reckoned a part of the inferior. The *portal* or *transverse fissure* (**porta hepatis**) is of an entirely different nature from the others. It is the *hilum* of the organ for the passage of the vessels and ducts; while the other fissures more properly deserve the name, being due to the pressure of the gall-bladder and of vessels. The portal fissure is from 4–5 cm. (1½–2 in.) long. It transmits the portal vein, the hepatic artery, the subdivisions of the gall-duct, the lymphatics, and

FIG. 1441.

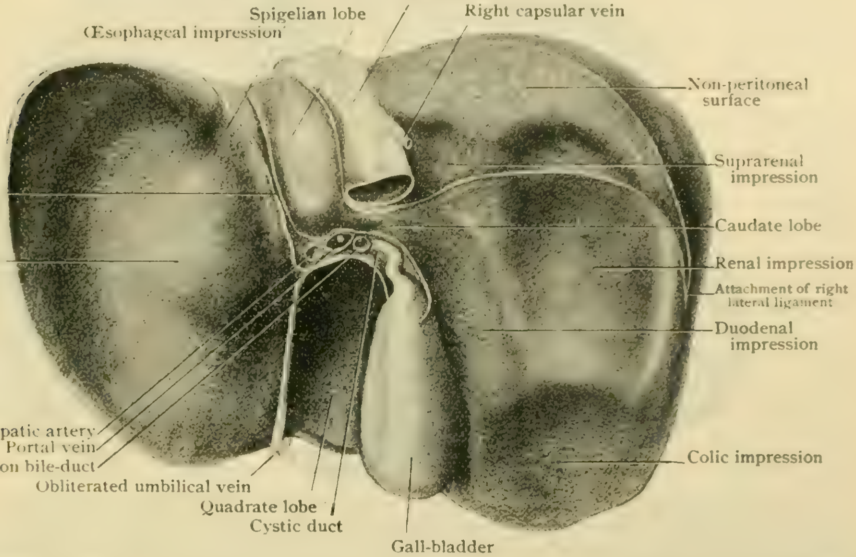


Posterior surface of same liver; peritoneal reflection indicated by white line.

the nerves, all enveloped in a mass of areolar tissue known as *Glisson's capsule*. The large portal vein is posterior. The hepatic artery lies before it on the left and the hepatic duct, formed by two chief tributaries, lies before it on the right. The lesser omentum is attached to the lips of the fissure outside of these structures. At its left end the portal fissure receives the *umbilical fissure*, which runs backward from the notch in the anterior border and contains the obliterated umbilical vein, in the adult known as the *round ligament*. This fissure is very often bridged over. Continuous with the umbilical fissure, the fissure of the ductus venosus ascends the posterior surface, only a small part of it being on the inferior aspect. In fœtal life it contained the blood-channel (*ductus venosus*) which established a short cut between the umbilical vein and the inferior vena cava; after birth it is reduced to a cord of fibrous tissue (**ligamentum venosum**). At the left end of the portal fissure the falciform ligament joins the lesser omentum, the latter being continued backward in the fissure of the ductus venosus. The *fossa for the gall-bladder* (**fossa vesicæ felleæ**) is a depression on the under surface of the right lobe, in which that organ rests. It may or may not indent the anterior border. Broad in front, the fossa narrows to a *fissure* behind that joins the right end of the portal fissure. The quadrilateral region on the under surface of the right lobe, bounded by the portal fissure behind, the border of the liver in front, the gall-bladder on the right, and the umbilical fissure on the left,

is the **quadrate lobe** (**lobus quadratus**). Behind the portal fissure the lower end of the lobe of Spigelius appears on the inferior surface, with the groove for the vena cava on its right and the fissure of the ductus venosus on its left. The **caudate lobe** (**processus caudatus**) is a rounded ridge, particularly developed in early life, running from the under side of the right lobe, just behind the right part of the portal fissure and in front of the vena cava, obliquely backward and to the left into the lower end of the lobe of Spigelius. A groove caused by the hepatic artery separates it from the tuber papillare. The caudate lobe overhangs the foramen of Winslow. In the adult it is sometimes rounded, sometimes sharp, and not always to be distinguished. The under side of the liver, being moulded over the neighboring organs, presents many irregularities dependent on their pressure. The posterior part of the under side of the right lobe is hollowed into the *renal impression*, a concavity fitting closely over the right kidney. The *suprarenal capsule* rests against the liver to the left of this, at the beginning of the caudate lobe on the under surface and also on the posterior surface. The first part of the *duodenum* rests against and moulds the under side of the right lobe between the renal impression and the gall-bladder. This area of con-

FIG. 1442.



Inferior and posterior surfaces of same liver. It must be clearly understood that the Spigelian lobe and vena cava are on the posterior surface, the limit of the inferior surface behind being the transverse fissure.

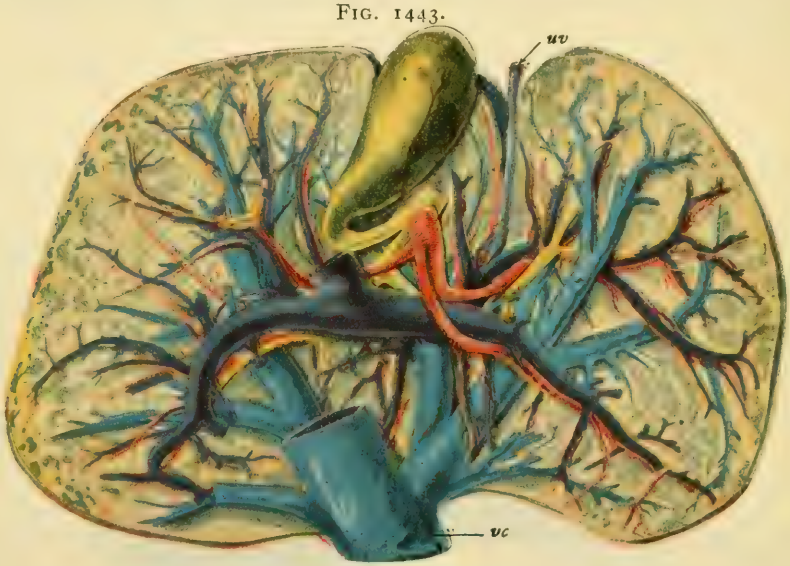
tact can hardly be called an impression, for the surface here is slightly convex. In front of the renal impression is a hollow for the *colon* of very varying size. It may be almost wanting, or it may be very deep. It may be confined to the right part of the under surface, or it may compress the front of the gall-bladder and indent the quadrate lobe, and even the left one. The under side of the right lobe presents also one or more occasional fissures which seem in the main to diverge from the right end of the portal fissure and from the fossa for the gall-bladder. They are more common in the fœtus, and some of them occur more or less frequently in anthropoid apes.[1] The under side of the left lobe is in general concave, resting against the fundus and anterior wall of the stomach. Near the posterior part of the umbilical fissure on the left lobe is a rounded prominence,—*tuber omentale*,—due to the growth of the liver against the non-resisting lesser omentum.

The Blood-Vessels.—The **portal vein**, some 15 mm. or more in diameter, divides into a right and a left branch, 10 mm. or over in diameter, of which the right is a little the larger and shorter. From the right end of the transverse fissure it runs

[1] Thomson: Journal of Anatomy and Physiology, vol. xxxiii., 1899.

backward in a curve to the right of the vena cava, keeping in the lower part of the liver and giving off successively a series of large branches to the front and right of the organ. Smaller branches arise from the sides of these. The right primary division soon gives off a large superior branch almost equal to itself, which describes a similar but smaller curve at a higher level. The general course of the left subdivision is towards the posterior angle of the organ, giving branches chiefly from its anterior side, and also one that supplies the greater part of the quadrate lobe. The lobe of Spigelius generally receives a chief branch near its lower end, which runs upward within it. This branch is most often from the left subdivision, but it may be from the right, or from the vessel directly behind the end of the portal vein. There are several systems of so-called *accessory portal veins* around the liver in the lesser omentum near the gall-bladder, about the diaphragm, and, most important, in the falciform ligament, where the *parumbilical veins* communicate with veins of the integument of the abdominal walls. These accessory vessels, small and inconspicuous under normal conditions, may become enlarged and important channels

FIG. 1443.



Portions of inferior and posterior surfaces of liver have been removed to show injected blood-vessels and bile-ducts. Vena cava is somewhat displaced forward, its course being more vertical when supported on posterior surface. Large upper branch of right division of portal vein is hidden by liver-substance. Portal vein and branches are purple; hepatic artery, red; hepatic veins and vena cava, blue; bile-ducts, yellow. *uv*, obliterated umbilical vein; *vc*, inferior vena cava.

for the return of the blood conveyed by the portal vein when the hepatic circulation is obstructed. Under such conditions the blood finds its way from the portal vein into the accessory veins and by the anastomoses of the latter into the general circulation.

The **hepatic veins** carrying off the blood from the liver arise as the *intralobular veins*, which empty into the *sublobular*, which join larger vessels converging towards the vena cava. At first the general direction of the small branches is parallel to that of those of the portal system of the same size; but the hepatic branches always travel alone. The direction of the large branches as they near the vena cava is at right angles to that of the portal. The arrangement of the hepatic branches is in the main like that of the portal, but near the edge of the liver we find more instances of the union of two rather small trunks meeting symmetrically like the arms of a Y. The main trunks of the right lobe run between the upper and lower branches of the portal. The upper end of the vena cava is considerably enlarged, and immediately below the diaphragm receives two large hepatic veins, a right and a left one, from 15 to 20 mm. in diameter. The latter is formed by two large branches that unite just before its end. Many small veins open into the vena cava at different

points along its course in the groove on the posterior surface of the liver, several coming from the Spigelian lobe. Sometimes quite a large branch from the right lobe opens at a low level. There is no such thing as an hepatic vein in the adult considered as an isolated structure. The ramifications of the portal and hepatic veins are inextricably mingled throughout, but in the main the branches of the latter lie above those of the former (Fig. 1443).

The **hepatic artery**, the nutritive vessel of the liver, divides into two branches which, together with the bile-duct, accompany the portal vein, the two arteries generally being on the same side of the vein. The hepatic artery gives off so many branches in its course as to be almost or quite of capillary size when it reaches the twigs of the portal vein that break up into the interlobular net-work. The blood conveyed by the hepatic artery is distributed by three sets of branches, the *capsular*, the *vascular*, and the *lobular*. The first ramify within the connective-tissue envelope of the organ and anastomose with branches from the internal mammary, phrenic, cystic, suprarenal, and sometimes right renal. The second supply the structures between the lobules, especially the walls of the ramifications of the portal vein and the bile-ducts. The third are small in size, and accompany the intralobular branches of the portal vein for a short distance within the lobule. There is no special system of veins to return the blood carried by the hepatic artery to the venous trunks outside the organ, the minute veins collecting the blood from the capsular and vascular sets being tributaries usually of the smaller branches of the portal vein. The blood passing through the lobular arterioles is emptied into the intralobular capillary net-work.

The **lymphatics** of the liver constitute a superficial and a deep set, the former lying beneath the peritoneum, the latter within the deeper interlobular connective tissue. The *superficial lymphatics* of the superior surface are arranged as three groups, posterior, anterior, and superior. The posterior group forms a right trunk which passes from the right triangular ligament across the right crus of the diaphragm to the cœliac lymph-nodes. Middle trunks—from five to seven in number—accompany the inferior vena cava to end in diaphragmatic nodes around the vein. Left trunks traverse the left triangular ligament and terminate in the œsophageal nodes surrounding the lower end of the gullet. The anterior group passes in the opposite direction to those just described and, crossing the anterior border of the liver, empties into the hepatic lymph-nodes within the lesser omentum. The superior group, the most important of those of the upper surface, ascends within the falciform ligament. A number of anastomosing vessels form a posterior trunk which crosses the inferior vena cava and enters the thorax with the latter, to end in the lymph-nodes around the vena cava. An anterior trunk accompanies the round ligament to the inferior surface and ends in the hepatic nodes at the hilum. Numerous middle trunks form vessels which pierce the diaphragm, to end in the anterior mediastinal nodes, becoming tributaries to the right lymphatic duct. The superficial lymphatics of the inferior surface include, on the right lobe, a posterior group, accompanying the vena cava into the thoracic cavity, to end in nodes around that vein, a middle group passing to the hepatic nodes around the cystic duct, and an anterior group terminating in the same nodes as the preceding. On the left lobe the vessels pass to the nodes of the hilum and about the hepatic artery. The lymphatics of the Spigelian lobe pass partly to the hilum nodes and partly to those surrounding the thoracic segment of the inferior vena cava. Communications exist between the superficial and deep lymphatics.

The *deep lymphatics* include two distinct groups, the one following the branches of the portal vein, the other accompanying the hepatic veins. The first descends within the capsule of Glisson in company with the portal vein and other interlobular vessels. On emerging at the hilum, the fifteen to eighteen trunks, arranged as two groups at the ends of the transverse fissure, join the hepatic nodes. The lymphatics which accompany the hepatic veins form a plexus surrounding the blood-vessels and proceed towards the vena cava, with which they pass through the diaphragm to enter the nodes lying immediately above the caval opening.

The **nerves** are chiefly derived from the solar plexus of the sympathetic with some fibres from the left pneumogastric which reach the liver by passing from the anterior surface of the stomach between the layers of the lesser omentum. The

sympathetic fibres accompany the hepatic artery, forming the hepatic plexus, to the transverse fissure, where, together with the fibres from the vagus, they pass into the liver along with the interlobular vessels, to the walls of which they are chiefly distributed. According to Berkley, the interlobular plexuses give off fine intralobular twigs which terminate between the liver-cells.

STRUCTURE OF THE LIVER.

In its fundamental arrangement the liver corresponds to a modified tubular gland, the system of excretory ducts of which is an outgrowth from the primary gut-tube. Early in fœtal life, however, the terminal divisions of the tubules unite to form net-works, after which the tubular character of the liver becomes progressively

FIG. 1444.

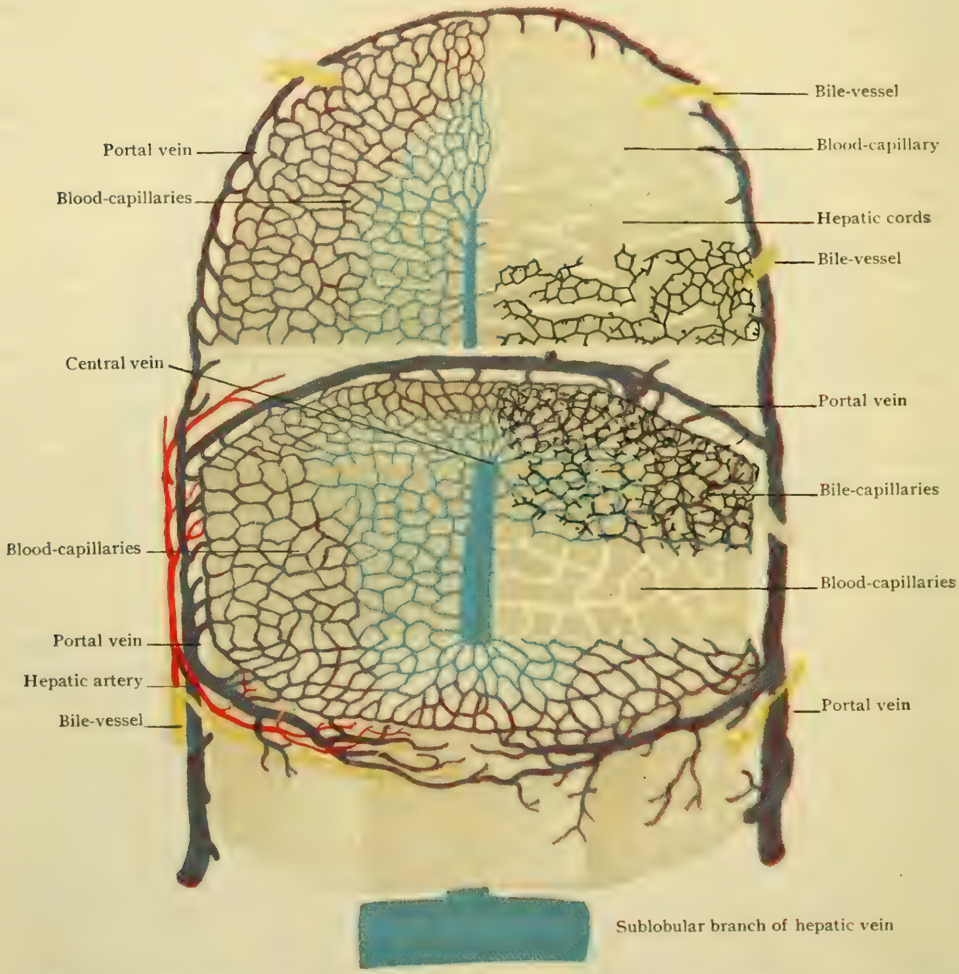


Diagram of hepatic lobule; portions of figure represent median longitudinal section of lobule; parts of transverse sections also shown. Branches of portal vein are purple; of hepatic artery, red; of bile-ducts, yellow. Intralobular bile-capillaries are black.

more masked by the intergrowth of the cell-cords and the large veins. Among some of the lower vertebrates, as in certain vermiform fishes or cyclostomes (*Myxine*), the primary tubular arrangement is retained.

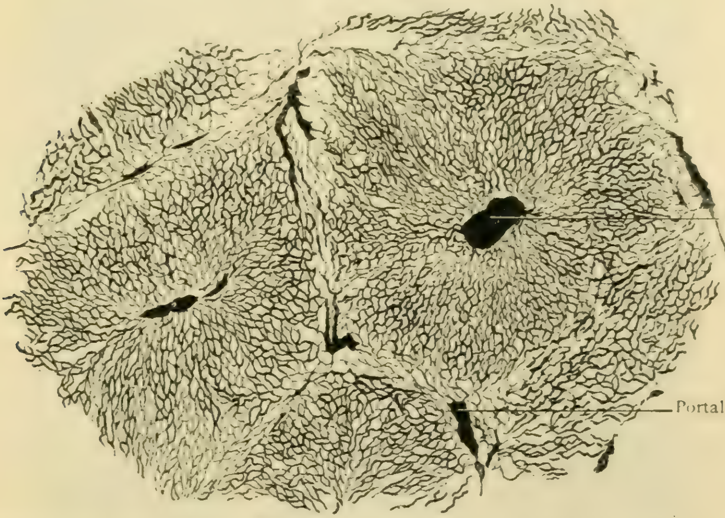
The glandular tissue composing the liver is subdivided into small cylindrical masses, the *lobules*, by the connective tissue which, in continuation of the fibrous

envelope, or *capsule*, investing the exterior, at the transverse fissure enters the organ and accompanies the interlobular vessels in their ramifications as the *capsule of Glisson* (capsula fibrosa). The distinctness with which the lobules are defined depends upon the amount of this interlobular tissue. In certain animals, notably in the hog, this is great, the lobules being completely surrounded and plainly distinguishable as sharply marked polygonal areas. In the human liver, on the contrary, the interlobular connective tissue is present in small amount, the lobules, in consequence, being poorly defined and uncertain in outline.

The Lobular Blood-Vessels.—Since the arrangement of the blood-vessels is the salient feature in the architecture of the fully formed lobule, it is desirable to study the vascular distribution before considering the disposition of the hepatic cells. As already described, the branches of the portal vein, the functional blood-vessel of the organ, ramify within the capsule of Glisson and encircle the periphery of the lobule; inasmuch as these vessels supply the divisions of glandular tissue with blood for the performance of their secretory rôle, they correspond with the interlobular arterioles of ordinary glands.

Numerous minute branches are given off from the interlobular ramifications of the portal vein which enter the periphery of the adjacent lobules and break up into

FIG. 1445.



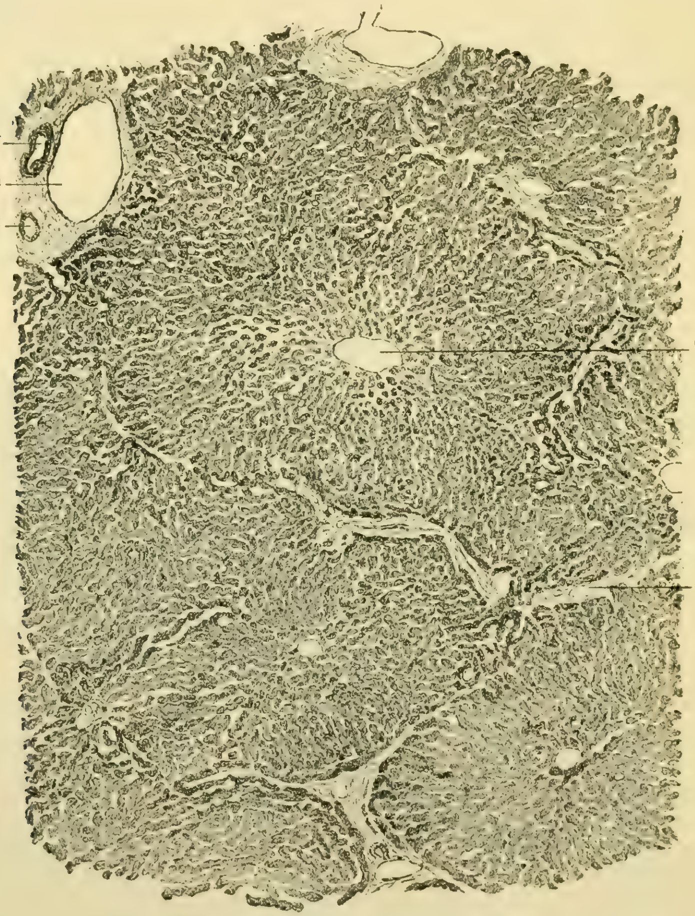
Section of liver injected from hepatic vein, showing intralobular capillary net-work. × 100.

the *intralobular capillary net-work*. The disposition of the latter is in general radial, the capillaries converging towards the middle of the lobule, where they join to form the *central* or *intralobular vein*, the beginning of the system of the hepatic veins by which the blood passing into the lobules is eventually carried into the inferior vena cava. The general course of the central vein corresponds to the long axis of the lobule (Fig. 1444), and hence in cross-sections of the latter the vein appears as a transversely cut canal towards which the capillary vessels converge (Fig. 1445).

The *capillary net-work* within the lobule is composed of channels with a diameter usually of about .010 mm.; the widest capillaries—some .020 mm. in diameter—are found in the immediate vicinity of the afferent and efferent veins, the narrowest occupying the intermediate area. The meshes of the vascular net-work vary from .015–.040 mm. in their greatest dimension, those at the periphery being broader and more rounded, while those near the centre are narrower and more elongated. The central vein occupies the long axis of the lobule and increases in size as it proceeds towards the *base* of the lobule, as the side of the latter through which the vein escapes is termed. It begins usually about midway

between the base and the opposite side of the lobule, by the confluence of the capillaries, which, after the central vein is formed, open directly into the latter at lower planes. In those lobules which form part of the exterior of the liver the central vein ascends almost to the free surface; otherwise its commencement is separated from the periphery by about one-half the thickness of the lobule. Immediately on emerging from the lobule the central vessel opens into the *sublobular vein*, which runs generally at right angles to its intralobular tubularies and along and beneath the bases of the lobules, the outlines of which are often seen through the walls of the vein. The channels for the sublobular veins are thus surrounded by the bases of the lobules, a single central vein returning the blood from each. The

FIG. 1446.



Section of uninjected liver, showing general arrangement of lobules, interlobular and intralobular vessels. × 120.

sublobular veins join to form larger vessels, which in turn unite and constitute the branches of the hepatic veins.

The Liver-Cells.—The meshes of the interlobular capillary net-work are occupied by the hepatic cells, the bile-capillaries, and a meagre amount of connective tissue. The cells are arranged as cords or trabeculæ which conform in their general disposition to the intercapillary spaces, which they completely fill. In a sense, the entire lobule consists of a solid mass of hepatic cells elaborately tunnelled by the radially coursing capillaries and their short anastomosing branches, the proportion of the space occupied by the vascular channels to that filled by the cells being approximately as one to three. When isolated, the liver-cells present a polygonal

outline and measure usually from .015–.025 mm. in their longest dimension. Each cell comes into contact with from six to nine other elements, the surfaces of contact being plane from mutual pressure. Always one side, often more than one, exhibits a shallow depression which indicates the surface of former contact with a capillary and emphasizes the intimate relation existing between the blood-vessels and the cells. The latter lie against at least one capillary and sometimes several, this relation being dependent upon the size of the blood-channels. The larger the latter, as at the periphery and near the centre of the lobule, the greater the number of cells with only one or two capillary facets; conversely, where the capillaries are of small diameter, the cells come into contact with three or four. The liver-cell consists of finely granular protoplasm which sometimes exhibits a differentiation into an outer and an inner zone. It is without a cell-membrane, although the peripheral zone of its cytoplasm is condensed, especially when it forms part of the wall of the bile-canaliculi. The nucleus, of vesicular form and from .006–.008 mm. in diameter, contains a small amount of chromatin and usually a nucleolus. Occasional cells are conspicuous on account of their large size, as well as the unusual diameter of

FIG. 1447.

Section of uninjected liver, showing cords of hepatic cells between capillary blood-vessels. × 450.

their nucleus. Such cells, according to Reinke,[1] soon undergo division and produce the double nucleated elements constantly encountered in sections of normal liver. Centrosomes have also been observed in resting hepatic cells. Particles of glycogen, minute oil droplets, and granules of bile-pigment are more or less constant constituents of these elements. The fat-containing cells are most numerous at the periphery of the lobule, those enclosing pigment particles near the centre.

The Bile-Capillaries.—These minute canals, representing the lumina of ordinary tubular glands, form a net-work of intercommunicating channels throughout the lobule closely related to the liver-cells. Whereas in the usual arrangement a single surface of several gland-cells borders the lumen, in the exceptional case of the liver the excretory channels are bounded by the opposed surfaces of only two cells, the bile-capillary occupying but a small part of the surfaces, on each of which it models a narrow, centrally situated groove. Moreover, not only a single surface of the hepatic cell takes part in bounding the canaliculi, but the latter are found between all surfaces where two liver-cells are directly in contact, so that each hepatic element comes into direct relation with a number of bile-capillaries. The latter,

[1] Verhandlung d. Anatom. Gesellschaft, 1898.

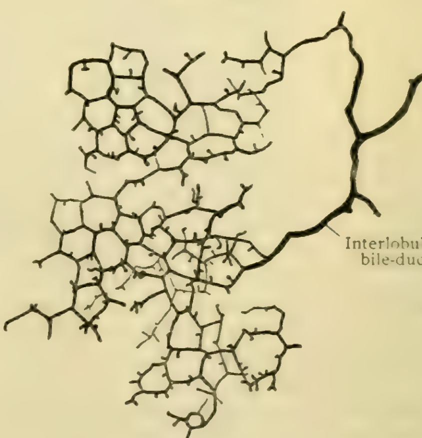
however, never lie on the narrow sides of the liver-cells opposed to the blood-vessels, the bile-canal never separating the blood-capillary from the cell. While the predominating direction of the bile-capillaries is radial and corresponds to the

FIG. 1448.

Section of liver in which both blood- and bile-capillaries have been injected; the latter surround the individual liver-cells. × 300.

similar general disposition of the cylinders or leaflets of hepatic tissue, the radial arrangement is converted into a net-work by the numerous cross-branches. The resulting meshes correspond in size with the individual liver-cells, which, in appropriate sections, often appear almost completely surrounded by the bile-capillaries. The latter possess no walls other than the substance of the liver-cells between which they lie. The diameter of the bile-capillaries, from .001–.002 mm., remains practically the same throughout the lobule until the canaliculi reach the extreme periphery. At this point the liver-cells abruptly diminish in height and are transformed into the low cuboidal cells lining the excretory tubes that pass from the lobule into the surrounding connective tissue to become tributaries to the larger interlobular bile-ducts.

FIG. 1449.

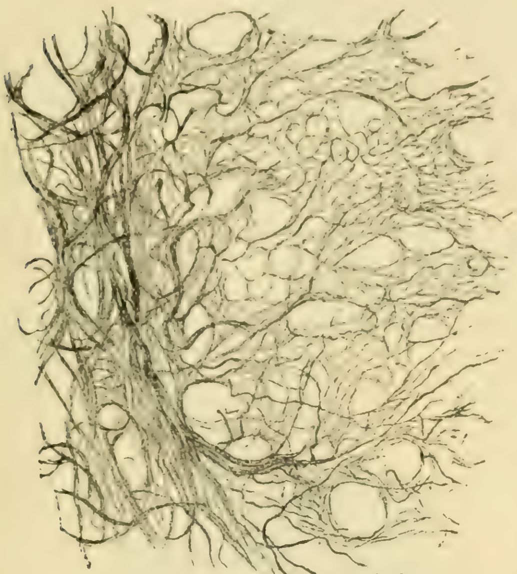


Section of liver treated by Golgi silver method, showing part of intralobular net-work of bile-capillaries. × 200.

The ultimate relations between the bile-capillaries and the liver-cells is still a subject of discussion. Based upon the evidence supplied by injections and silver impregnations, it is believed by some (Kupffer, R. Krause, and others) that extensions of the bile-capillaries normally exist within the substance of the cells, thus forming *intracellular secretion canaliculi*. The latter are sometimes pictured as ending in connection with minute dilatations or *secretion vacuoles*. While it seems certain that such appearances are not artifacts, or in the least due to changes after death of

the cells, the secretion vacuoles are probably due to the coalescence of minute drops of bile, exist only as transient details, and cannot be regarded as constant features of the hepatic cells. Holmgren[1] asserts the existence of "juice-canaliculi" within the liver-cells in addition to and independent of the intracellular secretion channels. Schäfer[2] has described nutritive channels within the liver-cells which communicate with the blood-capillaries.

FIG. 1450.



Artificially digested section of liver, showing supporting interlobular fibrous tissue and intralobular reticulum. × 230.

The **intralobular connective tissue**, or *reticulum*, consists of delicate prolongations of the fibrous tissue of Glisson's capsule which unite the blood-capillaries and cords of liver-cells. This tissue is very meagre in amount and forms a delicate reticulum extending between the blood-channels and the glandular elements throughout the lobule, and connects the peripheral fibrous tissue with the perivascular tissue that exists around the central vein. The intralobular connective tissue is so meagre that the liver-cells lie virtually in contact with the capillaries. Irregularly stellate elements, the *cells of Kupffer*, lie between the capillaries and the hepatic cells. They are probably endothelial plates, derived from the here imperfect walls of the capillary blood-vessels, permitting the blood to gain direct access to the liver-cells.

The **interlobular bile-ducts**, which receive the biliary canals that pierce the periphery of the lobule as the outlets of the intralobular net-work, accompany the

FIG. 1451.

Section of liver, showing interlobular tissue and vessels. × 160.

branches of the portal vein and the hepatic artery within the capsule of Glisson. These ducts, from .030–.050 mm. in diameter, constitute a net-work over the exterior

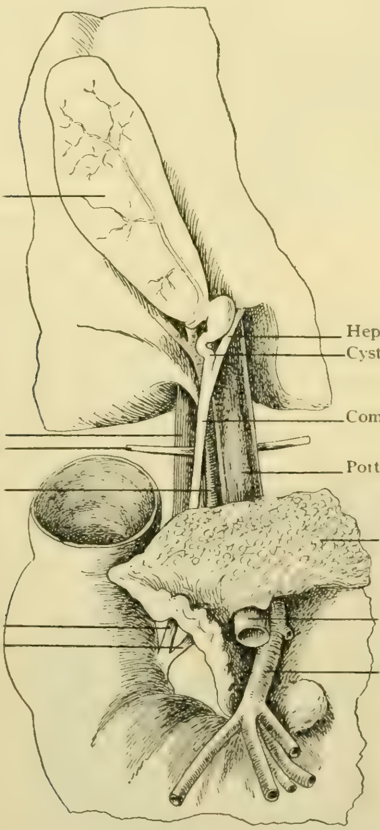
[1] Anatomischer Anzeiger, Bd. xxii., No. 1, 1902. [2] Ibid., Bd. xxi., No. 1, 1901.

surface of the lobule. They consist of a dense fibro-elastic coat lined with cylindrical epithelium, some .020 mm. thick, which latter is continued into the low cuboidal or flattened cells that form the lining of the excretory channels connecting the intralobular net-work of bile-capillaries with the bile-ducts. Beginning as the small vessels that surround the lobules, they become tributary to the larger bile-ducts, which increase in diameter as they approach the transverse fissure. In the vicinity of the latter these trunks join into the two main lobular ducts forming the hepatic duct. The largest bile-vessels possess bundles of unstriped muscle which in the hepatic duct are arranged principally as a longitudinal layer, supplemented by circular and oblique bundles (Hendrickson).

THE BILIARY APPARATUS.

In addition to the small interlobular bile-vessels already described, the system of canals receiving and conveying the secretion of the liver to the intestinal tract consists of the *hepatic duct*, the excretory tube of the organ ; the *gall-bladder*, a reservoir in which the bile accumulates during intervals of digestion; the *cystic duct*, the continuation of the bile-sac opening into the side of the hepatic duct ; and the *common bile-duct*, which, although formed by the union of the other two, is in structure and direction really the continuation of the hepatic duct.

FIG. 1452.



Portions of liver, duodenum, and pancreas, showing biliary and pancreatic ducts ; head of pancreas turned back.

The **hepatic duct** (ductus hepaticus) is formed below the hilum by the union of its two—a right and a left—chief tributaries. The latter issue from the portal fissure, one on each side, and generally unite with the hepatic duct nearly in the shape of a T, the last-named canal forming almost a right angle with each of its tributaries. Tracing the chief ducts into the liver, the left branch runs at first in front of the left division of the portal vein, while the right one usually crosses it. We have seen the hepatic duct issue from the right lobe and, forming a loop in the fissure, leave it with the left division of the portal vein, receiving branches along its convexity from the various parts of the liver. Sometimes the chief ducts are longer than usual, and meet to form the hepatic duct at an acute angle farther from the liver. The length of the hepatic duct, therefore, varies with these details, probably being usually from 20–40 mm. (¾–1½ in.), with a diameter of from 4–6 mm. It lies in the gastro-hepatic omentum, in front of the portal vein and to the right of the hepatic artery, and inclines downward to the inner side of the second part of the duodenum, resting previously on the top of the first part. The hepatic duct

ends at the point at which the cystic duct opens into it. The duct is lined with mucous membrane, covered with simple columnar epithelium, and presents many minute pits, into which open the orifices of numerous small tubular glands. Its walls consist of fibro-elastic connective tissue and unstriped muscular fibres. The latter, neither numerous nor separated into a distinct layer, are grouped for the most part into longitudinal bundles, but there are also circular and oblique ones.[1]

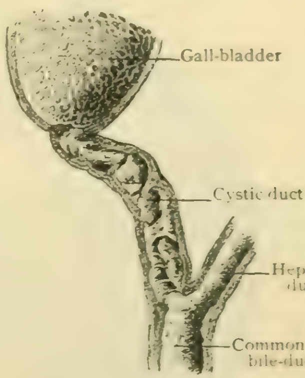
The **gall-bladder** (vesica fellea) is a pear-shaped receptacle for the bile, resting in its fossa on the under side of the liver, with the large end forward. The long axis runs also somewhat inward. The length is from 8–10 cm. (3¼–4 in.) and the capacity some 50 c.c. (about 1½ fl. oz.). It narrows to a point where it usually bends to the left and ends in the cystic duct without definite external demarcation. The bent terminal portion, or neck, about 1 cm. long, is more or less closely bound beneath the peritoneum to the side of the gall-bladder, so that before this is separated it sometimes looks as if the duct arose from the side of the latter.

The fundus of the gall-bladder lies near the end of the ninth right costal cartilage. The neck is at the right end of the portal fissure. Anteriorly the bladder rests on the transverse colon, behind which it lies first to the right of and then above the first part of the duodenum.

FIG. 1453.

Surface view of portion of mucous membrane of gall-bladder. × 12.

FIG. 1454.



Portion of gall-bladder and biliary passages laid open, showing surface of mucous membrane. Natural size.

The wall of the gall-bladder is very resistant, being composed of a mixture of fibrous tissue and of unstriped muscular fibres. Most of the latter are disposed circularly, but oblique and longitudinal ones are interwoven. The fibro-muscular tunic is lined by a layer of mucous membrane which is very adherent to it. The mucous membrane, covered with simple columnar epithelium, presents slightly raised ridges marking off a net-work of small irregular spaces some 5 mm. in diameter. The small bifurcated tubular glands are few and may be wanting. The bent portion, or neck, is separated from the bladder by a strongly raised fold. There are, or may be, one or two smaller folds within the neck, the separation of which from the duct is usually arbitrary.

Vessels of the Gall-Bladder.—*Arteries.*—The chief distribution of the cystic artery, a branch of the hepatic, is on the free under surface, which it approaches from the left, running on the cystic duct. There is a smaller branch which lies deeply on the right between the gall-bladder and the liver-substance. *Veins.*—The superficial veins join the cystic vein and empty into the right division of the portal vein. According to Sappey, a number of small veins run directly into the liver-tissue joining the portal system. The *lymphatics*, for the most

[1] For the musculature of the biliary apparatus, see Hendrickson : Johns Hopkins Hospital Bulletin, Nos. 90, 91, 1898.

part, empty into the nodes in the portal fissure. Some open into a node said to lie in the angle at the bend of the neck.

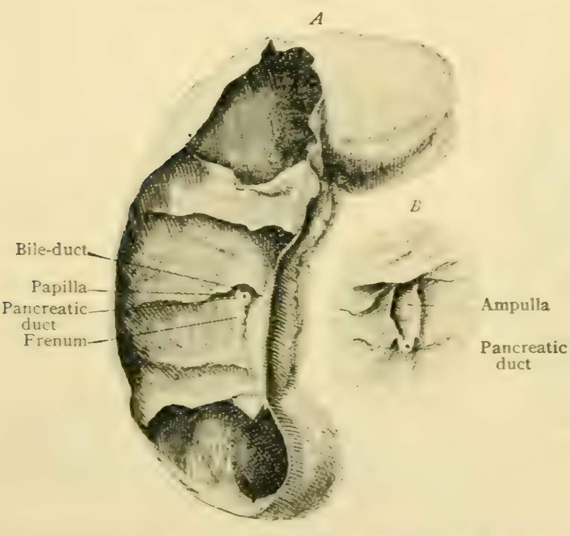
The **nerves** are from the solar plexus through the hepatic plexus.

The peritoneal relations of the bladder and ducts are considered with those of the liver (page 1721).

The **cystic duct** (**ductus cysticus**), 3 or 4 cm. in length, with a diameter of from 2–3 mm., passes in a fold of peritoneum from the neck of the gall-bladder to the gastro-hepatic omentum, where it joins the hepatic duct at an acute angle or, rather, opens into its side. It is said sometimes to present an enlargement at its end. In its natural condition it looks externally like the other ducts, but if distended and dried it presents a series of irregular folds giving the impression of a spiral fold which, in the adult at least, a closer inspection does not confirm.

Structure.—In structure the cystic duct presents much more of a muscular layer than the others. This is thickest at the upper part, and consists chiefly of circular fibres. These enter, especially near the beginning, the valvular folds of the mucous membrane, which is clothed with simple columnar epithelium. In the fœtus there is a fairly distinct spiral valve, most developed in the upper part, and, in fact, starting in the neck of the gall-bladder. Later the continuous spiral ridge (*valvula spiralis Heisteri*) usually atrophies and is broken up at many places, leaving detached folds with a semilunar outline and no longer distinctly spirally arranged. Little pockets also develop between them. Small tubular glands are few in the upper part, but plentiful in the lower.

FIG. 1455.



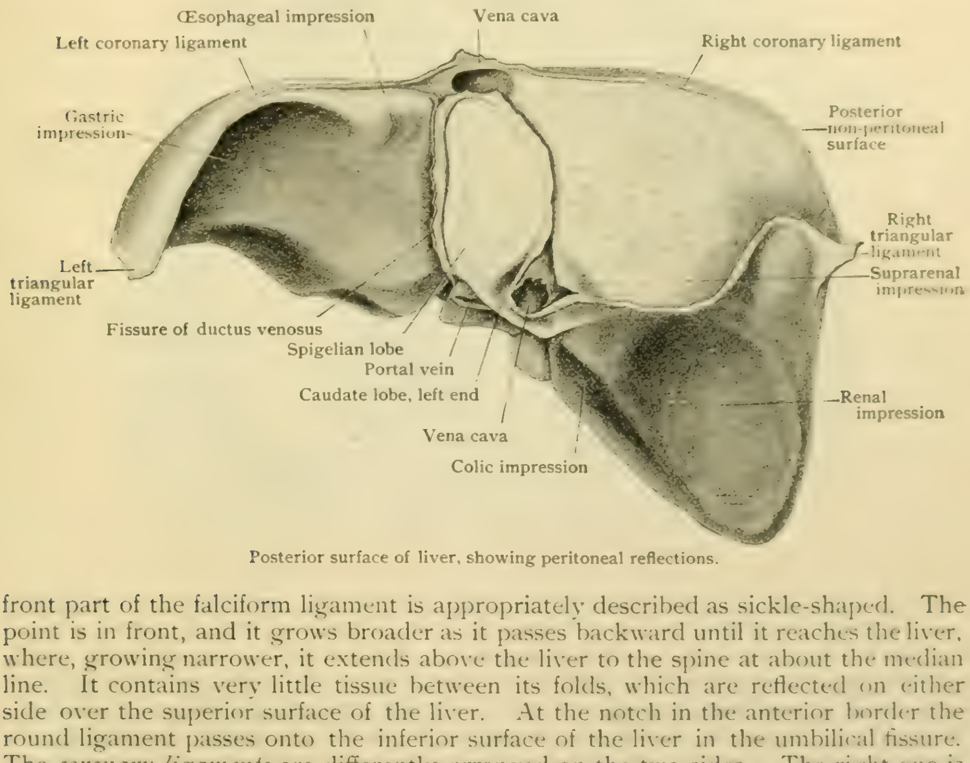
A, portion of duodenum, with anterior wall removed, showing entrance of bile and pancreatic ducts; *B*, papilla laid open, showing floor of ampulla. One-half natural size.

The **common bile-duct** (**ductus choledochus**) is about 7 cm. (2¾ in.) long. Its diameter is from 6–7 mm. at the commencement and rather less at the end. Beginning immediately below the transverse fissure, although conventionally regarded as formed by the union of the cystic and the hepatic ducts, being, in fact, the direct continuation of the latter, the common bile-duct passes downward between the layers of the gastro-hepatic omentum, in front of the foramen of Winslow, with the hepatic artery to its left and the portal vein behind. It descends along the postero-inner aspect of the bend joining the first and second parts of the duodenum, then along the inner side of the second part, where it is more or less surrounded by the head of the pancreas. Near its termination it meets the pancreatic duct and, in company with the latter, pierces the duodenal wall, which it traverses obliquely for the distance of some 15 mm., to empty into the duodenum at a papilla marking the common orifice of the two ducts. This *papilla* is situated near the posterior border of the internal aspect of the descending part of the duodenum, from 9–10 cm. (about 3½–4 in.) from the pylorus. In the natural condition it is not easy to find, being situated beneath a transverse fold and not being prominent in the shaggy mucous membrane. Its length undistended is only about 5 mm. When inflated or injected it is a prominent object more than twice as large. Moreover, it does not project freely, but lies on its side pointing downward, the surface next to the wall becoming free only very near its end. The orifice looks downward. It may be oval or circular, with a diameter of from 1–2 mm. A slight vertical fold, the frenum, often runs downward from the opening for the

distance of 1 cm. The structure of the common duct is much the same as that of the hepatic, containing but little muscular tissue and that not well defined. The papilla contains a fusiform dilatation, the *ampulla* (of Vater), which may be 1 cm. broad when distended. Into this the bile-duct and the duct of the pancreas usually open by a common orifice. Be these orifices common or distinct, each is surrounded by an accumulation of the circular muscular fibres which amounts to a sphincter. The glands, which are found throughout the common duct, are particularly large and numerous in the ampulla.

Ligaments and Peritoneal Relations.—The term "ligament," applied to the folds of serous membrane, is entirely inappropriate. It is in part retained, but the enumeration of five ligaments as separate entities is antiquated. The *round ligament* (**ligamentum teres hepatis**) is a cord of fibrous tissue, the remains of the obliterated umbilical vein, running from the umbilicus to the left end of the portal fissure. Its continuation, the ductus venosus, is represented by fibrous tissue (**ligamentum venosum**) in the fissure of that name. The round ligament lies against the abdominal wall for an inch or more above the navel and then passes backward in the free edge of the *falciform ligament*, a peritoneal fold representing the primary anterior mesentery, passing from the abdominal wall and diaphragm to the liver. The

FIG. 1456.

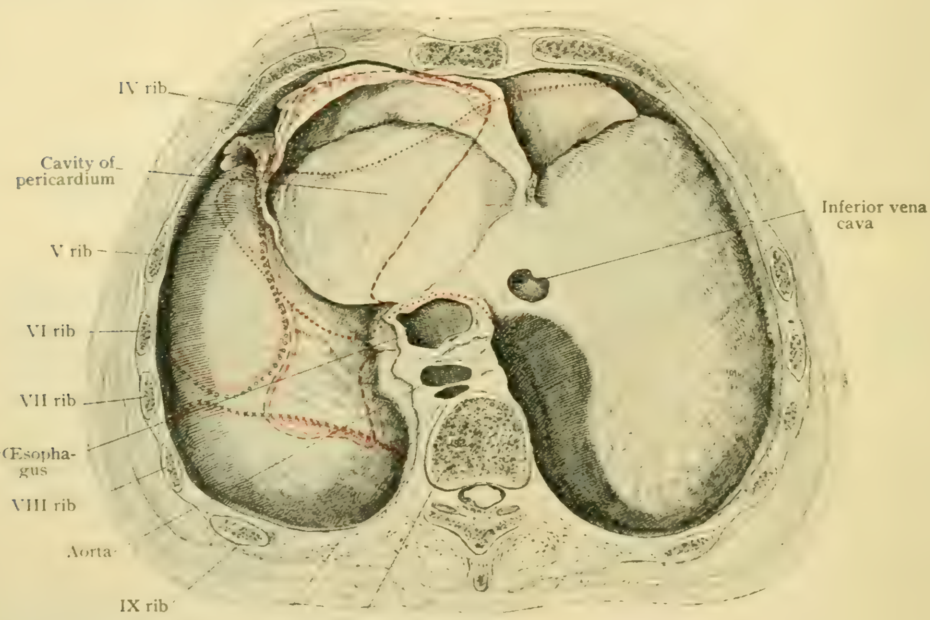


Posterior surface of liver, showing peritoneal reflections.

front part of the falciform ligament is appropriately described as sickle-shaped. The point is in front, and it grows broader as it passes backward until it reaches the liver, where, growing narrower, it extends above the liver to the spine at about the median line. It contains very little tissue between its folds, which are reflected on either side over the superior surface of the liver. At the notch in the anterior border the round ligament passes onto the inferior surface of the liver in the umbilical fissure. The *coronary ligaments* are differently arranged on the two sides. The right one is made by the two reflections onto the diaphragm from the upper and lower borders of the part of the posterior surface adherent to it. These come together at the right of that surface and are continued as a fold, the *right triangular ligament*, on the right surface, connecting it to the diaphragm in the flank by a line of attachment some 5 cm. long. On the top of the left lobe, but not on the posterior border, there is a small area without peritoneal covering, enclosed by the two folds of the *left coronary ligament*, of which the anterior is analogous to the right one, but the posterior begins at the left of the upper end of the fissure of the ductus venosus. They soon unite to form the *left triangular ligament*, which lies between the diaphragm and the top of the left lobe, being considerably longer than the right one.

On the under side of the liver the end of the round ligament lies in its fissure covered by a slight fold of peritoneum. The same is true of the gall-bladder. Sometimes the latter is more or less surrounded, and it may be almost completely so, hanging from the fossa by a fold. The *lesser* or *gastro-hepatic omentum* is a fold enclosing the vessels in the portal fissure and passing to the lesser curvature of the stomach and the first part of the duodenum. A secondary fold containing the cystic duct, the *duodeno-cystic fold*, joins it on the right. Near this it presents a free border forming the edge of the foramen of Winslow. On the left it runs along the fissure of the ductus venosus to the notch in the liver made by the passage of the œsophagus. There its left layer is reflected as the under one of the left coronary ligament, while the right layer descends along the left of the vena cava to join the right inferior coronary ligament. The posterior surface of the Spigelian lobe is covered with peritoneum which is almost surrounded by these lines of attachment, but is continuous, by means of the caudate lobe, with the serous coat of the under surface of the right lobe. Thus a pocket is roofed in behind the lobe of Spigelius.

FIG. 1457.



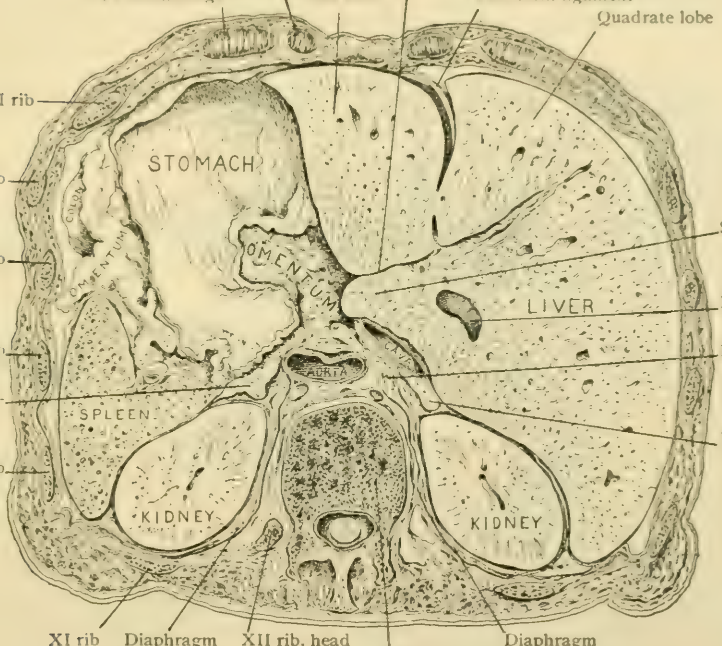
Transverse section at level of tenth thoracic vertebra, upper surface of diaphragm exposed, showing relation of viscera ; outline of liver, ... ; of stomach, – – – – –; of colon, o o o o o; of spleen, x x x x x.

The hepatic duct lies within the lesser omentum to the right and in front of the portal vein. It is joined by the cystic duct in its fold, already mentioned. As it leaves the gall-bladder, the duodeno-cystic fold is a distinct duplicature which joins the lesser omentum at an angle ; but at the lower part, where the cystic duct opens into the hepatic, the folds become one. The common bile-duct may be in the very lowest part of the lesser omentum, where it is attached to the postero-inner surface of the duodenum where the first part bends down to become the second ; but the relations are variable, and the common duct may have no peritoneal relation.

Position of the Liver.—The relations to other organs have been treated in the account of the surfaces. The relations to the walls of the abdomen can be given only in general, owing to the variations of both the organ and the thorax in size and shape. The liver lies under the dome of the diaphragm, which separates it from the ribs. Occasionally it extends across the whole breadth of the abdomen, but the left lobe may end at the left mammary line. The highest point is on the

right, where, after death, it reaches to the level of the sternal end of the fifth costal cartilage. It is doubtful whether in life the liver is ever quite so high. On the left it is about 1 cm. lower, and in the middle it is not more than 2 cm. lower still. The relation of the left lobe to the floor of the thorax varies considerably. If large, the organ may extend to the left wall, but this is rather uncommon. The liver may reach the front wall as far to the left as the mammary line, in which case it will be below nearly the whole of the floor of the pericardium, although it may not lie below the anterior part. It always passes just in front of the œsophageal opening. The inferior border rests against the posterior wall on the right, the diaphragm of course intervening, at the right border of the right kidney near the end of the last rib, on about the level of the second lumbar spine, and descends to the right along the line of the eleventh rib. At the mid-axillary line it begins to rise, following pretty closely the border of the thorax, to the ninth and tenth costal cartilages,

FIG. 1458.



Frozen section across body at level of twelfth thoracic vertebra.

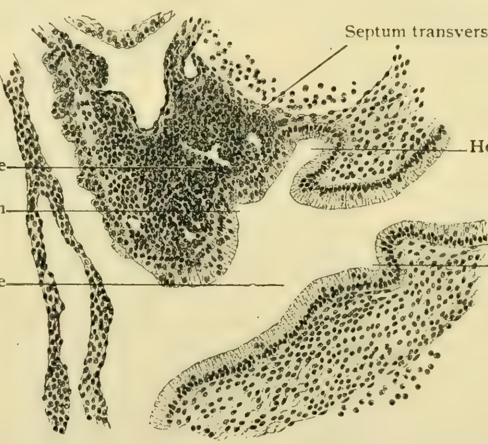
after which it crosses the epigastrium to strike the left costal arch at the eighth cartilage. The notch for the round ligament is a little to the right of the median line and the fundus of the gall-bladder at or near the end of the ninth right cartilage. It is usually crossed by a vertical line from the middle of the clavicle.[1] In the recumbent position the liver gravitates to the top of the abdomen, so that normally in the male no portion is left below the costal arch except near the middle. The inferior vena cava runs in a groove on the back of the organ, but the aorta, passing the diaphragm at a lower point, has the latter muscle between them. The vena cava pierces the diaphragm at the level of the body of the ninth thoracic vertebra. The lungs, especially the right, overlap the liver very considerably.

Development and Growth.—Very early, in the human embryo of 3.5 mm. in length, a groove-like evagination appears on the ventral wall of the gut-tube, immediately above the widely open vitelline duct. This evagination, the first indication of the hepatic anlage, extends into the primitive ventral or anterior mesentery

[1] Carmichael: Journal of Anatomy and Physiology, vol. xxxvii., 1902.

which connects the stomach and the duodenum with the anterior body-wall. The hepatic diverticulum grows forward and upward into the anterior mesentery until it comes into relation with the imperfect partition which partially separates the thoracic and abdominal divisions of the body-cavity. This partition, the *septum transversum*, primarily consists of lateral folds, projecting at right angles from the anterior mesentery, caused by the large vitelline veins traversing the anterior mesentery on their way to the sinus venosus of the early heart. The relation of these structures is more fully considered in connection with the development of the diaphragm (page 1701); for the present purpose it is sufficient to note that the liver-anlage early comes into relation with the septum transversum. The ventral portion of the primary liver-evagination, clothed with the entoblastic lining of the gut-tube, very soon differentiates into two diverticula: the one nearer the head, or *hepatic division*, produces the liver proper; the other, or *cystic division*, later becomes the gall-bladder and its duct. These divisions are gradually removed from the primitive duodenum by the growth of the primary diverticulum, which at one end becomes converted into a tube connected with the digestive canal and at the other bifurcates into the hepatic and cystic channels. This tube, evidently later the common bile-duct, is at first short and wide, but later rapidly lengthens.

FIG. 1459.



Portion of sagittal section of early rabbit embryo, showing liver-anlage and ducts. × 95.

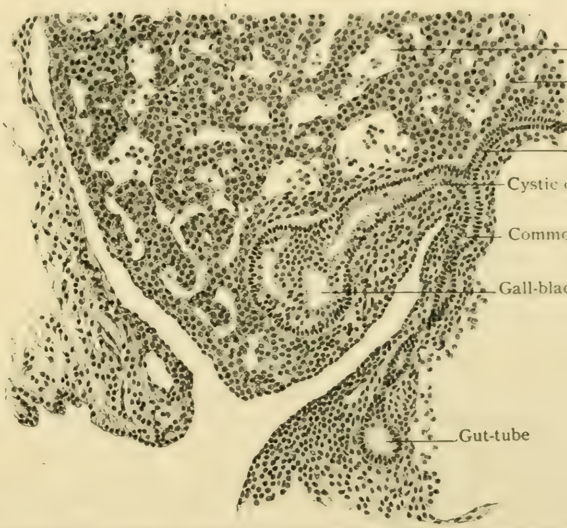
The cells lining the longer hepatic diverticulum undergo marked proliferation and produce the *liver-mass* which invades the septum transversum almost as far as the sinus venosus and surrounds the vitelline veins. The formation of the liver-mass follows at first the type of development seen in tubular glands, outgrowths of the hepatic tube branching and subdividing to form solid sprouts and buds composed of epithelial cells. In some of the lower animals, as the amphibians, the tubular type is retained in the adult organ; but in the higher forms, including man, the tubular character of the young liver is soon lost and replaced by the reticular arrangement produced in consequence of the growing together and union of the terminal divisions of the gland.

Coincidently with the formation of the net-work of glandular tissue by the junction of the cylinders of hepatic cells, the meshes of the reticulum become occupied by blood-vessels derived from vitelline veins. These are now represented at the hepatic anlage by venous stumps from which numerous afferent branches (*venæ hepaticæ advehentes*) penetrate the liver-mass to become the portal system. The division, subdivision, and union of these blood-vessels keep pace with the increasing complexity of the net-work of hepatic cords, the intergrowth of these constituents eventually leading to the intimate relations between the hepatic secreting tissue and the intralobular capillaries seen in the fully developed organ. The cell-trabeculæ composing the primary hepatic net-work are partly solid and partly hollow; the

latter, with a portion of those without a lumen, are converted into the system of bile-canals, while the remaining cylinders give off additional sprouts which reduce the intervening meshes and increase the solidity of the organ. The solid cylinders of secreting tissue at first contain no bile-capillaries. The latter are hollowed out between two adjacent cells as extensions of the meanwhile differentiating biliary ducts. Differentiation of the developing liver into lobules does not occur until the beginning of the fourth fœtal month, by which time the larger blood-vessels and bile-ducts become surrounded by condensations of the mesoderm which form the capsule of Glisson.

The details of the formation of the hepatic blood-vessels are considered in connection with the development of the veins (page 928). It may be here mentioned, however, that the primary circulation of the liver, including the portal vein the intralobular capillary net-work, and the hepatic veins, is derived from the modification of the vitelline veins, in conjunction with their tubularies from the digestive organs. The relations of the placental circulation to the liver are secondary. The left umbilical vein for a time pours practically all the blood returned from the placenta into the portal vessel; when the latter is no longer capable of receiving the entire amount of the placental blood, the development of the ductus venosus brings relief by establishing a short cut by which the excess of placental blood passes directly into the ascending vena cava.

FIG. 1460.



Portion of sagittal section of rabbit embryo, showing developing liver and ducts. × 95.

The development of the gall-bladder and its duct proceeds, as already indicated, from the more caudally placed cystic division of the primary hepatic diverticulum. The subsequent changes include the growth and expansion of the terminal portion of the primitive cystic canal to form the bile-sac, its elongated stalk becoming the cystic duct, while differentiation of the entoblastic lining and the surrounding mesoblast produces the distinguishing details of the fully formed organs.

With the conversion of the primary liver-mass into the more definite organ, the relations of the ventral mesentery, into which the early liver-anlage grows, become changed. For a time the developing liver lies within the septum transversum, but later, with the formation of the diaphragm, it separates from the latter and projects into the body-cavity. This projection results in a differentiation of the ventral mesentery into three parts: (*a*) the middle portion, the layers of which become separated by the growing liver to form its serous investment; (*b*) the anterior portion, which extends from the front surface of the liver to the umbilicus and becomes the falciform ligament enclosing the umbilical vein, later the ligamentum teres; (*c*) the posterior portion, which stretches between the digestive tube and the liver and, as the gastro-hepatic, or lesser omentum, maintains similar relations and encloses the biliary ducts.

In the fœtus the liver is relatively immense, especially at an early period. At the fourth fœtal month it practically fills the whole of the top of the abdomen. Although it increases absolutely after this, it relatively diminishes, but at birth is still considerably above the relative size of the adult organ, forming approximately one-

eighteenth of the entire body weight. The left lobe reaches across the stomach so as to be in contact with the spleen. The tubercle at the lower extremity of the Spigelian lobe and the caudate lobe are relatively large. In the infant there is little connective tissue in the organ, which is very friable and also easily moulded on the surrounding structures. At birth the weight of the liver is about 150 gm. (5 oz.).

PRACTICAL CONSIDERATIONS: THE LIVER, GALL-BLADDER, AND BILIARY PASSAGES.

The Liver.—Anomalies in the position of the liver occasionally occur, as in "transposition," when the whole organ may be on the left side; in such cases the spleen and other asymmetrical abdominal viscera (and frequently, but not necessarily, the thoracic organs) will also be found to be transposed. "Accessory" lobes are not uncommon and have been mistaken for new growths.

The *shape* of the liver may obviously be affected by compression exerted through the parietes. The chief type of the so-called "lacing" or "corset" liver is marked by a transverse groove separating the main body of the organ from a prolongation downward of the anterior portion, especially of the right lobe, which may reach to below the umbilical level. This portion has been mistaken for a movable right kidney. Knuckles of intestine may lie between it and the anterior abdominal parietes and prevent the recognition of its continuity with the liver by either palpation or percussion.

Movable liver (*hepatoptosis*) is a condition in which, through stretching of the tissues and structures which normally retain it in place beneath the arch of the diaphragm, it sinks by gravity to a lower level. It has then been mistaken for various forms of abdominal or renal tumor and for movable kidney. Hepatoptosis is often associated with displacements or abnormal mobility of other abdominal viscera. Traction of the liver on the suspensory ligament is said to produce a fold of skin which hides the lower part of the umbilicus (Glenard).

The structures most potent in holding it in its proper position are, in the order of their importance: (*a*) the attachment of the hepatic veins to the inferior vena cava, (*b*) the coronary ligaments and the cellulo-vascular bands in and between its layers, (*c*) the fibrous tissue near the vena cava and on the non-peritoneal posterior surface of the right lobe, (*d*) the muscular wall of the abdomen (keeping the intestinal mass pressed upward beneath the liver), and (*e*) the lateral and "suspensory" ligaments.

Coincidently with the descent of the viscus it undergoes a rotation or tilting forward so that its diaphragmatic surface is in contact with the abdominal wall.

Hepatopexy consists in suturing such a movable liver in its normal position by stitches which may be variously placed, but the most useful of which seem to be those which unite the round ligament and liver-substance with the anterior abdominal wall near the xiphoid cartilage (Francke, Treves).

The normal relations of the liver to the diaphragm and the abdominal parietes cause it to be much influenced—especially as to its circulation—by the respiratory and other movements associated with energetic exercise; hence the congestion of the organ resulting in "biliousness," or even in jaundice, seen in cases in which, from accident or disease, persons who have led active lives are confined to bed. In walking, and more markedly in horseback riding, the compression of the organ between the diaphragm and the upper—or respiratory—segment of the abdominal wall which takes place during deep inspiration is aided by its downward movement from gravity. It has been suggested (Jacobson) that such movement must slightly open the inferior vena cava, which is then immediately compressed by the following upward movement,—during expiration,—thus directly influencing the systemic venous current and with almost equal directness that in the hepatic veins.

In deep inspiration the anterior edge of the liver descends from under cover of the lower ribs, and in very thin persons may be palpated. A similar descent occurs when a reclining is exchanged for an erect position.

The direct connection between the gastro-intestinal and the portal circulation causes the latter to be markedly affected by the use of alcoholic or other irritants and

by the amount and character of food taken. Drinking and overeating thus exaggerate the periodic physiological congestions of the liver and often result ultimately in organic changes. Of course, passive congestion is likely to follow valvular disease of the heart, emphysema, pulmonary cirrhosis, or any condition in which the right heart is engorged, the backward pressure through the vena cava reaching the hepatic veins and their sublobular tributaries. The thin interlobular and perihepatic connective tissue, known as Glisson's capsule, which closely invests the ducts and vessels, is commonly affected in chronic irritation of the liver, especially that form due to alcoholic excess, and in some infectious diseases, notably the specific fevers and syphilis. Its anatomical relations explain the usual sequence of phenomena. Proliferation of the portions surrounding the terminal branches of the portal vein causes obstruction which, either alone or aided by the concurrent toxæmia, results in congestion and catarrh of the stomach and intestines, in enlargement of the spleen and pancreas, and later in ascites.

As the obstruction increases, a collateral circulation is often established to relieve the portal congestion by means of communication between (*a*) the accessory portal veins (particularly those in the falciform ligament) and the diaphragmatic, para-umbilical, and epigastric veins; (*b*) the veins of Retzius and the retroperitoneal veins; (*c*) the hemorrhoidal and the inferior mesenteric veins; (*d*) the gastric and the œsophageal veins. An operation has been employed to establish a better and more satisfactory compensatory circulation in cases of cirrhosis by effecting adhesions between the surfaces of the liver and the spleen and the diaphragmatic peritoneum, on the one hand, and the parietal peritoneum and omentum, on the other.

When compression of the liver is carried beyond physiological limits, as from contusion or from forced flexion, *rupture* results. This is more frequent in the liver than in the other abdominal viscera on account of its size, its friability, its fixity, its close diaphragmatic and parietal relations, and its great vascularity. A similar disjunction of liver-substance may occur from a fall on the feet from a height. It is grave in proportion to the extent of the rupture and to its involvement or non-involvement of the peritoneal covering. Ruptures confined to the liver-substance,—*i.e.*, not reaching the surface,—and moderate in extent, are not infrequently recovered from. The commonest seat of rupture of the liver is near the falciform and coronary ligaments, with which the rupture is apt to be parallel. If they are extensive enough to reach the surface of the organ, death often results from hemorrhage, the intimate association of the hepatic substance with the thin-walled vessels preventing their retraction or collapse. Hemorrhage is also favored by the direct connection of the valveless hepatic veins with the vena cava and by the absence of valves in the portal veins. According to the situation of the rupture, the blood may be poured into the general peritoneal cavity; into that portion of it known as the subhepatic space, and bounded below by the transverse mesocolon; or into the retroperitoneal space behind the liver and ascending colon. The local symptoms will vary with the situation of the collected blood.

Wounds of the liver should be considered with reference to its relations to the parietes, especially on the right side, where, on account of its greater bulk, it is more often injured. Except at the subcostal angle, where a small part of the anterior surface lies against the abdominal wall (the lower edge being on a line between the eighth left and the ninth right costal cartilages), the lower ribs and costal cartilages surround the liver. Thus stab wounds must pass between them, while fracture of the ribs with depression may penetrate the interposed diaphragm and then the liver-substance. Anteriorly, a little internal to the mammary line, the liver may reach to the fourth intercostal space or even quite to the level of the nipple, and may be directly wounded throughout that area. Laterally it is not usually found above the sixth interspace. Posteriorly a stab wound through the sixth, seventh, or eighth intercostal space, or even down to the level of the tenth dorsal spine, would penetrate four layers of pleura, the thin concave base of the right lung, and the diaphragm before reaching the liver. Still lower, the base of the lung may escape, but a wound of the liver may involve the two layers of pleura of the costo-phrenic sinus and the diaphragm. Of course, the alterations in position of the liver during inspiration and expiration, and according to the position of the body, must be

remembered in obscure cases before basing a diagnosis upon the situation of the external wound.

In bleeding from the liver after either rupture or stab wound, or during operations, temporary occlusion of the portal vein and hepatic artery may be secured by pressing them between the finger and thumb, the former being placed just within the foramen of Winslow and the latter externally on the gastro-hepatic omentum.

Enlargement of the liver, if uniform (congestion, multiple abscess, perihepatitis, fatty degeneration, hypertrophic cirrhosis), causes a bulging of the right lower ribs and their cartilages and an increase of the area of *absolute percussion dulness.* The upper limits of the latter should normally be found at the sterno-xiphoid junction in the median line, the sixth intercostal space in the right mammary line, the seventh rib in the axillary line, and the lower border of the ninth rib in the scapular line. A modified dulness is obtained posteriorly over the area where the lung overlaps the liver, down to the level of the ninth rib. The lower level of the dulness—and thus of the liver itself—is in the mid-line, half-way between the sterno-xiphoid junction and the umbilicus, at or a little below the costal margin in the mammary line, on a level with the tenth and eleventh ribs laterally and opposite the eleventh dorsal vertebra posteriorly. At this point it is continuous with the lumbar dulness due to the thickness of the spinal muscles, the quadratus lumborum, the kidneys, and the perirenal fat.

In localized enlargements, as from tumor, abscess, or hydatids occupying the upper surface of the right lobe, the diaphragm is pushed upward and the upper limit of the percussion dulness raised, the lower limit remaining temporarily unaffected, the area of dulness being thus increased.

In emphysema or pneumothorax both limits are lowered (as they are also in empyema, although in that condition the liver-dulness merges into that of the pleural abscess), and in phthisis, collapse or retraction of the lung, or abdominal meteorism both limits are raised, the total area of dulness remaining unchanged in these cases. Of course, in atrophic disease the area is diminished and, as in cases in which the whole liver is drawn or pushed up, or there is free gas in the abdominal cavity, there may be tympany over the right lower ribs.

Abscess of the liver may be due to infection through the portal system, as from dysentery or hemorrhoids, or from typhoid fever, colitis, or appendicitis; or through the general blood-supply, as from osteomyelitis or cranial trauma. In addition to the usual symptoms of suppuration, it, like many other liver troubles, is sometimes characterized by pain in or above the right shoulder. This is thought to be explained by the facts that (*a*) the right lobe is far more commonly affected, (*b*) the phrenic contributes to the nerve-supply to the liver and is derived partly from the fourth cervical, and (*c*) the supra-acromial nerve is a branch of the latter. Other evidence showing relations between the supra-acromial and phrenic nerves, *e.g.*, hiccough in shoulder arthritis, makes this explanation seem reasonable.

Hepatic abscess may open (*a*) *inferiorly* into the stomach, colon, duodenum, or right kidney, or into some portion of the peritoneal cavity,—either the subhepatic space, the general cavity, or the lesser cavity *via* the foramen of Winslow; (*b*) *superiorly* into the pleura, lung, or bronchi, or into the pericardium; (*c*) *posteriorly* into the retroperitoneal space and the loin; (*d*) *anteriorly* on the surface of the body, sometimes following the remains of the umbilical vein to the umbilicus.

The resistance of the ribs, intercostal muscles, and diaphragm makes pointing in other directions of rare occurrence. Pus may invade the suprahepatic (subdiaphragmatic) space or the liver itself from above the diaphragm. Many empyemas have taken this course. Nephric or perinephric abscess on the right side may extend to the liver.

Hydatid cysts are more common in the liver than elsewhere, as the embryo of the egg of the tænia echinococcus, freed from its shell by digestion, readily penetrates the gastric and intestinal vessels, and is very likely to enter a tributary of the portal system and thus be carried direct to the liver, where it multiplies and develops into the mature hydatid. Spontaneous evacuation of the cysts may occur in any of the directions already mentioned.

In opening an hepatic abscess or hydatid cyst the liver must be reached, as in

other operations, by traversing either the peritoneal or the pleural cavity. In doubtful cases, or when there is an anterior swelling, a vertical incision in the mid-line through the right rectus or at its outer edge, beginning at the costal margin and prolonged downward, will permit of exposure of the liver and evacuation of the abscess or cyst, the peritoneal cavity being walled off by gauze packing. If the liver is approached above the lower ribs or posteriorly, it will be necessary to resect a portion of one or more ribs, suture the diaphragmatic and parietal pleuræ together or to the thoracic wound, and then incise the diaphragm. If the liver is to be reached laterally,—*i.e.*, in the right axillary line,—resection of the tenth rib will disclose the diaphragm with no intermediate layer of pleura. Penetration of the diaphragm opens the peritoneal cavity and permits access to the lower and outer portion of the right lobe.

Cancer of the liver is usually secondary (to metastasis through the portal system), multiple, and diffuse. When primary and consisting of a single nodule, excision may be attempted. In controlling hemorrhage, the friability of the liver-substance makes ligation of separate vessels difficult, and it may be necessary to employ an elastic tourniquet, the cautery, gauze pressure, or all three.

Lymphatic involvement secondary to hepatic cancer may be found in the œsophageal, mediastinal, lumbar, or omental glands.

The relation to the œsophageal lymphatics is also shown by a case in which hepatic abscess followed a mediastinal œsophagotomy.

The Gall-Bladder.—This sac may be absent, as is normally the case in some of the lower animals; it may be congenitally of hour-glass shape; it may be bifid; it may communicate directly with the liver by a "hepato-cystic" duct; it may be transposed (in conjunction with other viscera), and in one such case cholecystostomy for gall-stones was performed on a gall-bladder lying on the left side.

Wounds of the gall-bladder are rare.

Rupture of the gall-bladder may occur from traumatism to the abdominal parietes; it is favored by distention of the viscus and by enlargement of the liver, both of which carry the gall-bladder downward to a less protected position and favor the direct transmission of the force. Extravasation of bile into the general peritoneal cavity follows. It may be sterile, and may then act merely as an irritant, causing an extensive plastic exudate, but is apt to be fatal by setting up septic peritonitis.

If operation discloses such a rupture, it may be remembered (1) that the extravasated bile first flows into the large peritoneal pouch bounded above by the right lobe of the liver, below by the ascending layer of the transverse mesocolon covering the duodenum internally, externally by the peritoneum lining the parietes down to the crest of the ilium, posteriorly by the ascending mesocolon covering the kidney, and internally by the peritoneum covering the spine; (2) that this pouch can be easily and thoroughly drained through a lumbar incision; and (3) that it is capable of holding nearly a pint of fluid before it overflows into the general peritoneal cavity through the foramen of Winslow or over the pelvic brim (Morison).

Distention of the gall-bladder is ordinarily due to (1) inflammatory obstruction of the cystic duct (cholangitis); (2) mechanical obstruction of the cystic duct, usually from the impaction of gall-stones; (3) acute cholecystitis, (*a*) catarrhal, (*b*) suppurative; or (4) obstruction of the common duct from tumor or, much more rarely, from impaction of a calculus in that duct before the gall-bladder has become inflamed, contracted, and formed adhesions. The gall-bladder itself may be the primary seat of a malignant growth. It is impossible to feel the normal gall-bladder through the abdominal wall.

Enlargement of the gall-bladder from any cause usually takes place in a downward and forward direction on a line which, beginning a little below the ninth costal cartilage, crosses the linea alba just below the umbilicus. If the liver is of normal size, the neck of the gall-bladder is about opposite the ninth costal cartilage. If the liver is enlarged, the gall-bladder will be so much depressed that its neck may be on a level with, or even lower than, the umbilicus. The rounded, pear-shaped, or gourd-like fundus can usually be felt, movable laterally, and sometimes with a palpable groove between it and the lower edge of the liver. The swelling descends

during inspiration. If the cause of the enlargement is inflammatory and adhesive peritonitis has resulted, the tumor may be fixed so that it does not move with respiration ; but there is then, especially in acute cases, apt to be pain and tenderness over the swelling or at a point between the ninth costal cartilage and the umbilicus.

It may be mentioned here that the diagnosis between the chronic form of gall-bladder disease and movable kidney is not always easy ; that the two conditions not infrequently coexist in the same person ; and that the possibility of error is increased by the fact that they are each met with much oftener in women than in men, and that the right kidney is far more frequently movable than the left.

The anatomical explanation is that in women with flabby abdominal walls either tight lacing or a relatively slight jar or strain tends to produce displacement of both the kidney and the liver, the latter resulting in tension or angulation and consequent obstruction of the bile-ducts. The two conditions also act reciprocally, descent of the liver causing displacement of the kidney, which, through its traction upon the duodenum, tends to obstruct the bile-ducts.

A movable kidney, as compared with an enlarged gall-bladder, is less influenced by respiration ; has a wider range of motion, especially in the long axis of the body ; is more influenced by position ; slips backward towards the loin instead of upward beneath the liver ; is less often visible and less frequently tender on pressure, which is apt to cause a sickening sensation analogous to testicular nausea (page 1951).

Acute cholecystitis (phlegmonous) is due to infection. The colon or typhoid bacillus, or the pneumococcus, streptococcus, or staphylococcus, may reach the gall-bladder either through the blood, as during a pneumonia, by lymphatic and vascular channels, as after an appendicitis, or through the intestine and bile-ducts, as in some of the post-typhoidal cases.

The symptoms are (*a*) generalized abdominal pain, due to the association of the cystic plexus, through the cœliac, with the superior mesenteric ; (*b*) pain below the right costal margin passing towards the epigastrium,—*i.e.*, referred to the cœliac and solar plexuses,—and towards the right scapular region, from the association of the phrenic and the supra-acromial nerves through the fourth cervical (page 1758); (*c*) rigidity over the right hypochondrium, due to the connection between the splanchnics and the intercostals ; (*d*) nausea, vomiting, and prostration, due at first to the close relation of the cystic plexus with the cœliac and solar plexuses, later to toxæmia and to peritonitis ; (*e*) localized tenderness at the junction of the upper and middle thirds of a line drawn from the ninth rib to the umbilicus,—*i.e.*, over the fundus of the inflamed gall-bladder; (*f*) distention and paresis of the intestines, due sometimes to a localized peritonitis affecting the hepatic flexure of the colon and simulating an acute intestinal obstruction.

Gangrene has occurred, emphasizing the clinical and pathological resemblance of this condition to appendicitis, but is very rare, illustrating the importance of one anatomical factor—the scanty blood-supply—in causing the gangrene which is so exceedingly common in that disease (page 1682). Bacterial infection and absence of drainage (and therefore tension) are two conditions predisposing to gangrene, present in both cases ; but the third—thrombosis of the nutrient vessels—determines the frequency of gangrene in the appendix, which is supplied by only one nutrient artery, and is relatively ineffective in the case of the gall-bladder, which has a rich blood-supply through the large cystic artery and also through the anastomoses of its branches with the hepatic vessels where the gall-bladder is fixed to the liver (Mayo Robson).

Empyema of the gall-bladder (suppurative cholecystitis), due usually to cholelithiasis, obstructive catarrh, and infection through the ducts, may discharge itself in various directions determined by the occurrence of inflammatory adhesions. The most common communication is with the cutaneous surface, the pus having been evacuated through the parietes beneath the costal margin in 50 per cent. of Courvoisier's 184 cases, and in the umbilical region, where it was conducted by the suspensory ligament, in 29 per cent. The colon or duodenum beneath, the subphrenic space or pleural cavity above, and the right prenephric peritoneal pouch—walled off by adhesions—have been favorite seats for the spontaneous evacuation of pus

and gall-stones in old cases of empyema of the gall-bladder. Its anatomical relations to surrounding structures and spaces should therefore be carefully studied.

Cholelithiasis.—As the normal expulsive efforts of the muscular walls of the gall-bladder are usually aided by the contraction of the abdominal muscles during exercise, gall-stones are more commonly found in persons of sedentary habits, in invalids, and in females, especially in multipara. Tight lacing, by depressing both liver and gall-bladder, as well as kidney (*vide supra*), is also a distinct predisposing cause. Bacterial infection with the colon or typhoid bacillus, and more rarely with other organisms, is, however, a frequent exciting cause of the hypersecretion and epithelial proliferation which lead to the formation of gall-stones.

The presence of stones in the gall-bladder may be unaccompanied by symptoms, or may cause the development of such phenomena as either have no distinct anatomical bearing (biliary fever and secondary visceral lesions) or as have already been considered (abscess of the liver, empyema of the gall-bladder, fistulæ, etc.). There are mechanical accidents, however, connected with the emigration of the stones which will be considered from the anatomical stand-point in relation to the biliary ducts.

The Cystic and Common Bile-Ducts.—The cystic duct is the narrowest portion of the biliary passages. Its calibre would permit the passage of a probe through it into the hepatic duct, but the irregular folds of its mucous membrane (sometimes regarded as constituting a "spiral valve,"—the valve of Heister) usually effectually prevent satisfactory probing. Its muscular fibres are better developed than are those of the other biliary ducts. The passage of a stone through it is attended by (1) *colicky pains* of the sort usually associated with violent muscular contraction; (2) *continuous pain resembling that due to an acute cholecystitis* (the two conditions being often mistaken one for the other), and due (*a*) to the slow progress of the stone in the cystic duct, in which it takes a rotary course owing to the arrangement of the mucous folds; (*b*) to the acute inflammation which usually accompanies an attack; and (*c*) to the stretching and distention of the gall-bladder by retained secretions (Osler). The pain may be even more intense, and is apt to be accompanied by (3) *vomiting*, (4) *profuse sweating*, and (5) *great depression of the circulation*, all due to reflex irritation of the sympathetic plexuses and the pneumogastric. There may be (6) a *rigor*, either purely nervous or due to retained secretions and a concurrent lithæmic inflammation. In the latter case there will be (7) *fever* from the accompanying toxæmia.

If the stone passes into the intestine, all the symptoms usually disappear. It may cause (8) *intestinal obstruction*, and is a far more common factor in the production of this condition than are enteroliths. Of 149 cases of this type of obstruction, 133 were due to gall-stones and only 16 to enteroliths, and 10 of these had gall-stone nuclei. Although a stone of considerable size may pass through the duct, those large enough to bring about intestinal obstruction usually enter the duodenum by ulceration. If the stone becomes impacted in the cystic duct, (9) *dilatation* of the gall-bladder with mucus (hydrops) occurs; or (10) *cholecystitis*, acute or chronic, may follow (*vide supra*). Calcification and atrophy of the gall-bladder are not uncommon sequelæ.

The stone may pass into and obstruct the *common duct*. This is about three times the diameter of the cystic duct, and, therefore, many stones which have given rise to the above symptoms pass through it easily. If a stone permanently occludes it, there will usually be deep and persistent jaundice, clay-colored stools, vague and dull hepatic and shoulder pain, rarely colicky in character, and absence of septic phenomena and of enlarged gall-bladder, the latter symptom occurring in not more than 10 or 12 per cent. of cases of calculous common-duct obstruction. A stone may pass as far as the ampulla of Vater and act as a "ball-valve," in which case there will be variable jaundice and ague-like paroxysms of chills, fever, and sweating, accompanied by hepatic pains and gastric disturbance (Osler). The mechanical effect of a stone in such a position, plus the resulting nerve irritation and infective cholangitis, sufficiently explains these phenomena.

Occlusion of the common ducts may occur from other causes, as stricture following ulceration due to stone, the presence of lumbricoid worms, echinococci, etc., or

even of foreign bodies which have been swallowed. Pressure from extrinsic causes is far more frequent, however, as a cause of occlusion. It may be due to carcinoma of the lymph-nodes in the transverse fissure, secondary to rectal or to gastric cancer ; or to enlargement of the head of the pancreas from new growth or from inflammation ; or to aneurism of branches of the cœliac axis.

In these cases, contrary to what is found in occlusion from gall-stones, the gall-bladder is usually enlarged.

Congenital obliteration of the ducts may occur.

Operations on the Gall-Bladder and Biliary Ducts.—A vertical incision, at least 7.5–10 cm. (3–4 in.) in length from the costal margin downward, made over the middle of the right rectus muscle, the fibres of which are separated, will usually satisfactorily expose the gall-bladder. If it is necessary to open either of the ducts, the incision may be prolonged upward in the interval between the xiphoid cartilage and the costal cartilages. If the liver is then drawn downward from beneath the ribs and rotated upward and outward and the transverse colon is drawn downward, the subhepatic space will be well exposed, bounded by the under surface of the liver above and externally, the colon and transverse mesocolon below, and the duodenum and pyloric end of the stomach internally. In this position, especially if a sand-bag has been placed beneath the back opposite the liver, so as to push the spine forward, the cystic and common ducts are brought close to the surface, the angle between them is effaced, the region of entrance into the duodenum is in full view, and incision for drainage of the gall-bladder (cholecystostomy), or for the extraction of a calculus either from the gall-bladder (cholelithotomy) or a duct (choledochotomy), or for the removal of the gall-bladder (cholecystectomy) becomes possible. If there are many and troublesome adhesions, the fundus and body of the gall-bladder being buried and not recognizable, it is well first to locate the hepatico-duodenal fold of peritoneum,—the right border of the lesser omentum,—in which the common duct may be traced from its duodenal termination upward, the portal vein lying behind it and the hepatic artery to the left. The cystic and hepatic ducts may then be identified. The ducts may often best be examined by passing the forefinger of the left hand through the foramen of Winslow, the back of the surgeon being turned towards the patient. The duct, the portal vein, and the hepatic artery may thus easily be grasped between the thumb and finger. The close relation of the lower end of the common duct to the vena cava should be remembered in operations upon it. This portion may be reached, if necessary, as in some cases of stone impacted at the duodenal papilla, by opening the second portion of the duodenum and slitting up the duct as it lies in the inner and posterior wall of the intestine, where it may be felt as a cord.

The duct may be reached at a higher point by an incision through the peritoneum to the right of the duodenum, the latter being freed posteriorly and drawn towards the median line.

In cases in which the common duct is permanently obstructed a portion of the duodenum or jejunum may be anastomosed with the gall-bladder (cholecystenterostomy) by direct suture.

THE PANCREAS.

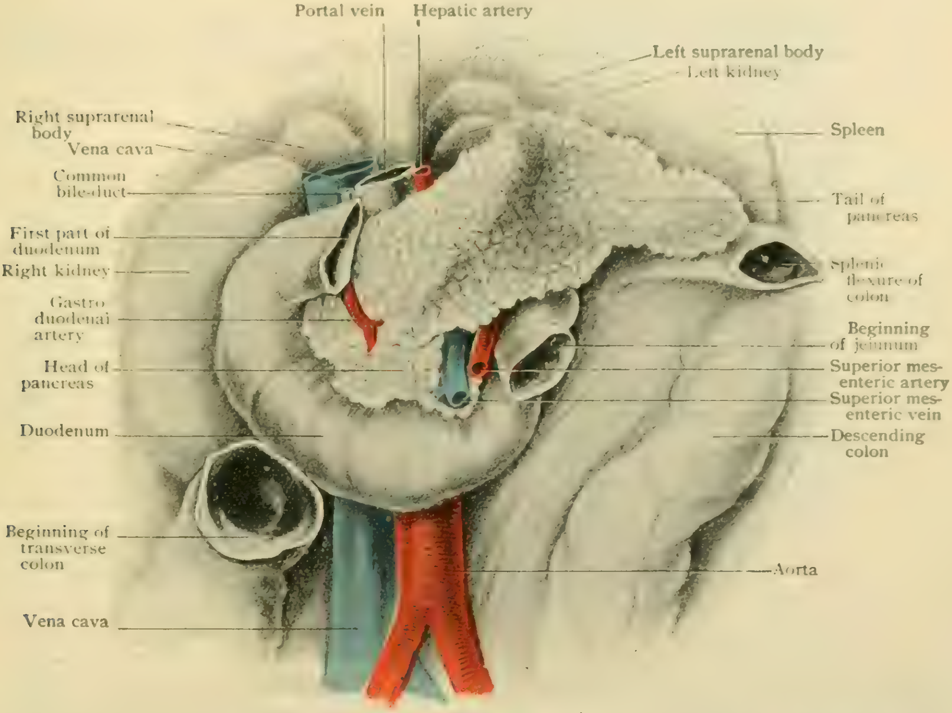
The pancreas, the "abdominal salivary gland," lies moulded across the spinal column with its head on the right, enclosed in the loop of the duodenum, and its tail on the left, in contact with the spleen. It is of a light straw color running into red, according to the amount of blood within the organ. The weight ranges from 30–150 gm. (1–5 oz.) or even more. The specific gravity is about 1045. The length *in situ* is approximately 15 cm. (about 6 in.). It consists of an enlarged descending part on the right, the *head*, and of a long body placed transversely, which is needlessly divided into *neck*, *body*, and *tail*. When the organ is removed from the body and straightened it somewhat resembles a revolver in shape, the head being the handle. The gland, however, is so modelled by the surrounding parts that its true form is seen only in its undisturbed position, or after hardening *in situ* before removal from the body.

The **head** (caput pancreatis) is a rounded but irregular disk packed into the space between the first and third parts of the duodenum, and lying close against the

left of the second part. It overlaps both the second and third parts anteriorly, and tends to insinuate itself behind them. We have seen it overlapping the fourth part also. So much has been said of the variations of the duodenum (page 1644) that it must be evident that the head of the pancreas can hardly have any certain size or shape. Its diameter from above downward is probably rarely less than 7 cm. and may be greater. It is separated from the neck by a groove on the front of the gland for the gastro-duodenal branch of the hepatic artery. It rests behind on the inferior vena cava, sometimes on the right renal vein, and may approach the right suprarenal body. It is opposite the first and second lumbar vertebræ and often a part of the third lumbar vertebra.

The **body** (corpus pancreatis), including the neck and tail, is prismatic, having a *posterior*, an *antero-superior*, and a narrow *inferior surface*. It is so tortuous in its natural position as to seem shorter than it is. Starting on the right of the spine at the level of the first lumbar vertebra, it passes around it to the left and backward and again forward to the spleen, which it may or may not cross. Towards its end it also turns downward.

FIG. 1461.



Anterior aspect of pancreas *in situ*; the organ is exceptionally broad, and covers more of left kidney than usual; peritoneum has been removed.

The **neck** is the part (2–3 cm. in length) which crosses the portal vein with a forward convexity, being deeply grooved by the vein on its posterior surface. The left extremity of the body is the **tail** (cauda pancreatis), the end of which is very variable in form. If it lies in front of the spleen it is more or less pointed, but if it ends against the gastric surface of that organ it may have a true terminal concave surface, fitting it accurately (Fig. 1461).

The **posterior surface** has first (from the neck towards the left) the deep groove for the portal vein, which may be entirely surrounded by glandular tissue. Beyond this it lies on the vena cava, then on the aorta between the cœliac axis and the superior mesenteric artery, which groove it above and below. It next lies on the left pillar of the diaphragm, the left suprarenal capsule, and the left kidney. The left end may have a concave surface resting on the gastric surface of the spleen, or

it may extend across this surface, or rest on the basal one. There are two horizontal grooves on the posterior surface. The lower, which is the longer and deeper, is caused by the splenic vein. It extends from the left end to the groove for the portal vein, inclining to the lower border as it approaches it. A smaller groove for the splenic artery lies above the former from the left to near the aorta.

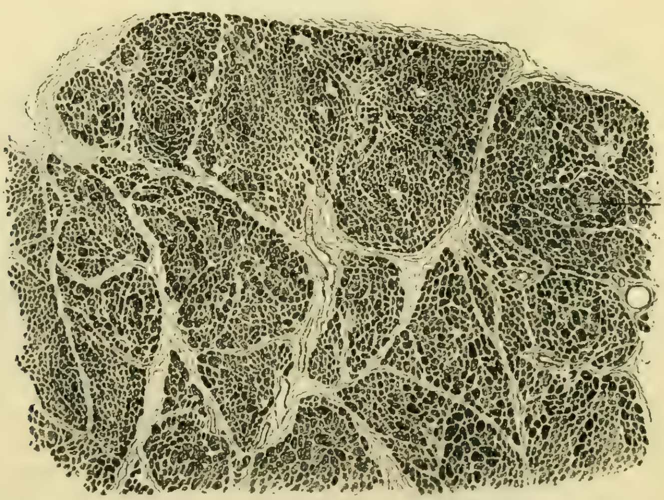
The **antero-superior surface,** the largest of the three, slants downward and forward, presenting a concavity which forms a part of the stomach-bed. It is on the average some 4 cm. broad, but may exceed 5 cm. There is often a swelling—the *omental tuberosity* (**tuber omentale**)—to the left of the neck opposite the aorta. This is behind the lower end of the vertical part of the lesser curvature of the stomach, and is in contact with that organ rather than with the omentum.

The **inferior surface,** the smallest, rarely as much as 2 cm. in breadth, rests on the lower layer of the transverse mesocolon. It is rounded and irregular, except where it lies above the duodeno-jejunal fold, where it is smooth and concave. To the right of this it is grooved by the superior mesenteric artery.

The **borders** at which the surfaces meet call for no special description beyond that both the inferior ones are grooved by the superior mesenteric artery and the upper by the cœliac axis.

Structure.—While agreeing in its general structure with other serous salivary glands, as the parotid, the pancreas differs in certain particulars. The most important of these are the tubular, rather than saccular, form of the alveoli, the marked differentiation of a granular zone in the protoplasm of the secreting cells, the absence of specialized intralobular ducts, and the presence of the islands of Langerhans.

FIG. 1462.



Section of pancreas under low magnification, showing general arrangement of lobules. × 30.

The chief pancreatic duct gives off numerous lateral interlobular branches which are lined with a single layer of columnar epithelium, about .006 mm. in height, the direct continuation of that clothing the large ducts, in which the cells are from two to three times as tall. The canals springing from the interlobular ducts after entering the lobules possess a layer of flattened epithelial plates some .012 mm. long by .003 mm. high, and correspond to the intercalated or intermediate ducts. The intralobular canals being wanting, the relatively long intermediate ducts pass directly into the tubular alveoli, within which their attenuated epithelium protrudes as the *centro-acinal cells.* The relation of the latter to the usual glandular elements lining the alveolus is peculiar, the thinned-out and spindle duct-cells being surrounded externally by the secreting cells.

The tubular *alveoli* of the gland, often tortuous and sometimes divided, possess a well-defined membrana propria against which lie the *secreting cells.* The latter

are usually of a blunted pyramidal shape, although many aberrant forms are seen, with an average length of about .010 mm. During functional inactivity their cytoplasm exhibits two well-differentiated zones : an inner one, next the lumen, which is highly granular, and an outer one, next the basement membrane, which is free from granules and at times almost homogeneous. The round or oval nucleus occupies the external area. The relative breadth of these two zones varies with the functional activity of the cells. During fasting, when the latter are stored with zymogen particles, the granular zone is very broad and the outer homogeneous one correspondingly narrow. With beginning discharge of the pancreatic secretion during digestion, the granular zone diminishes and reaches its minimum, almost disappearing when the gland is exhausted. The return of the latter to a condition of rest is accompanied by the formation and gradual accumulation of a new store of zymogen particles until the granular zone is again restored to its maximum. Occasionally in fixed tissue the parietal cells exhibit within their cytoplasm a body termed the *paranucleus* (Nebenkern). The latter is of uncertain form, often singularly round and indented, and smaller than the nucleus in the vicinity of which it usually lies. The nature and significance of this body are still undetermined, some observers regarding it as a derivative from extruded nuclear material, the paranucleus, in turn, being concerned in producing the zymogen-granules. *Intercellular secretion-capillaries* have been demonstrated in the alveoli of the pancreas. They extend between the cells for some distance, but do not reach the basement membrane surrounding the acini. Intracellular secretion-vacuoles are also demonstrable at times by means of Golgi stains, but are temporary and cannot be regarded as constant details of the cells (Ebner).

FIG. 1463.

Section of pancreas, showing interlobular connective tissue with vessels and duct surrounded by tubular alveoli. × 200.

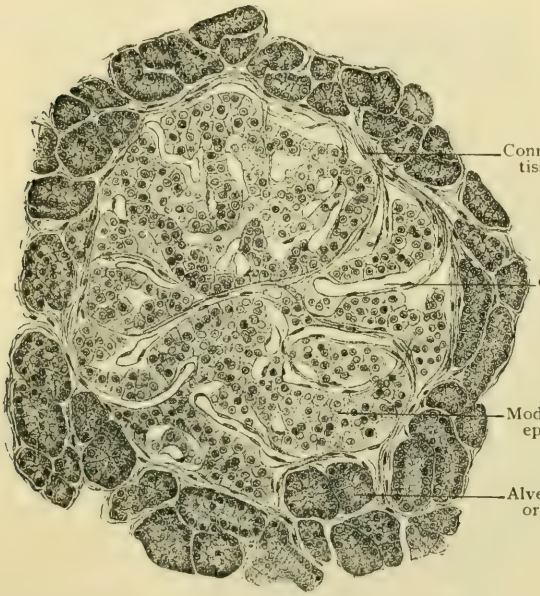
The **interalveolar cell-areas**, or *islands of Langerhans*, appear as small collections of cells, some .3 mm. in diameter, lying between the tubular acini, from which they are separated by a delicate envelope of connective tissue. These cell-areas are constant features of the pancreas, not only of man, but likewise of a wide range of animals representing mammals, birds, reptiles, and amphibians. Their distribution within the pancreas is by no means uniform, since, as has been shown by Opie,[1] while about equally numerous in the head and adjacent part of the body of the organ, they may be almost double in number towards the tail. The cells composing these masses, although developed from the same tissue which gives rise to the usual glandular elements of the pancreas, differ from the latter in being smaller, polygonal rather than pyramidal in form, less granular, and undifferentiated into the characteristic zones usually seen in the pancreatic cells. They are arranged as a net-work consisting of solid cords or trabeculæ, the meshes of which are occupied by blood-capillaries of large size ; the whole recalling the arrangement of hepatic tissue. No extension of the system of excretory tubes has been demonstrated within these cell-islands, secretion-capillaries being therefore wanting. The significance of the islands of Langerhans has long been a subject of dispute, but in view of their isola-

[1] Johns Hopkins Hospital Bulletin, September, 1900.

tion from the surrounding glandular tissue and their close relation with the blood-vessels, the opinion is held by many that they produce some substance which passes directly into the blood and may be regarded, at least provisionally, as concerned in "internal secretion."

The Pancreatic Ducts.—The gland is surrounded by a fibrous sheath which sends in many processes dividing it into small lobules. The chief excretory canal in the adult is the *duct of Wirsung* (**ductus pancreaticus**), which, beginning near the end of the tail, runs through the middle of the pancreas towards the right, and bends downward as it passes through the head. Branches sprout from the main duct at right angles, which receive bunches of smaller ramifications. The diameter of the duct near its end is about 5 mm. It descends just in front of the common bile-duct to the wall of the duodenum and empties in common with it at the papilla (Fig. 1455). Its termination very often is in the floor of the ampulla (**diverticulum duodenale**), so that the papilla presents but one opening. The tributary ducts of the head are larger than the others. A particularly large one—the *duct of Santorini* (**ductus pancreaticus accessorius**)—is in the early stage of development the chief duct of the head, and consequently of the gland. In the adult it usually descends from the right to empty into the duct of Wirsung as the latter turns downward. In about half the cases, according to Schirmer,[1] it opens independently into the duodenum, some 3 cm. above the papilla and more anteriorly. The orifice is usually surrounded by a small raised ring. Even when so terminating it retains its connection with the duct of Wirsung. Thus fluid in the body of the pancreas may in such cases pass into the duodenum by either opening, and fluid in the duct of Santorini may pass either directly into the gut or through the duct of Wirsung. The canal of Santorini may be no more than an insignificant side branch of the other, or it may be the chief, or sole, excretory duct.

FIG. 1464.



Section of pancreas, showing island of Langerhans. × 200.

Relations to the Peritoneum.—Although developed in both the posterior and the anterior mesenteries, the pancreas, owing to the changes by which the spleen on the left and the descending part of the duodenum on the right have come to lie against the posterior abdominal wall, is entirely retroperitoneal. The posterior surface, with the possible exception of the end of the tail, which may be surrounded by peritoneum, is attached to the parts behind it by connective tissue. The layers of peritoneum covering the antero-superior and the inferior surfaces meet to form the transverse mesocolon, which is attached along the border between these surfaces, and is continued on the right across the head, and may sometimes rise towards the left onto the antero-superior surface. The gastro-pancreatic fold, made by the gastric artery, crosses the gland upward from a point a varying distance below the cœliac axis.

Vessels.—The *arteries* are many small branches derived from the splenic, hepatic, and superior mesenteric. As the splenic runs along the top of the posterior

[1] Beiträge zur Geschichte und Anatomie des Pancreas, Basel, 1893.

surface it sends a series of branches into the upper part of the body and tail. The hepatic runs along the top of the front of the head and neck, doing the same. In the groove between head and neck the gastro-duodenal sends the superior pancreatico-duodenal across the front of the gland, supplying chiefly the head. The superior mesenteric artery, just after its origin, sends from its right the inferior pancreatico-duodenal. This vessel gives off a larger branch running to the right to meet the superior pancreatico-duodenal on the front of the head, and sends a smaller branch to the left along the lower surface. Sometimes the two branches which meet across the head enclose it by a similar anastomosis behind. The *veins* follow in the main the arteries. They are all tributaries of the portal system, and some open directly into the portal vein. The *lymphatics* are many. Most of them run to the cœliac and splenic plexuses. A small group of lymph-nodes is situated on the front of the head.

The **nerves,** composed chiefly of non-medullated fibres, are from the solar plexus, by way of the cœliac, splenic, and superior mesenteric plexuses.

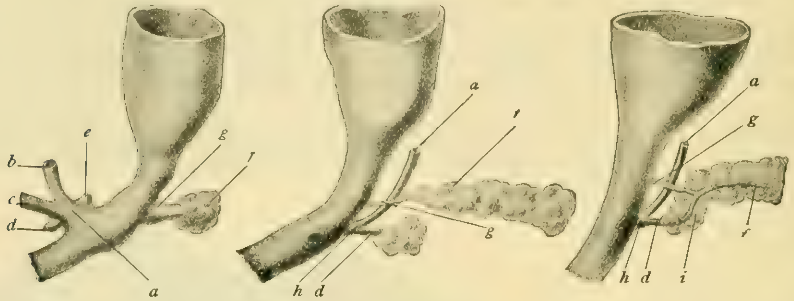
FIG. 1465.

Section of injected pancreas, showing intralobular capillary net-works; also convolutions of islands of Langerhans. × 50.

Development.—The human pancreas develops from two separate anlages, a dorsal and a ventral one. The former, which appears by the fourth fœtal week, is a direct outgrowth from the primitive duodenum. The ventral anlage, slightly later in its formation, develops as two outgrowths, one from each side of the early bile-duct, and is therefore not strictly a direct derivative from the gut. The left ventral outgrowth soon disappears, leaving the right one connected with the bile-canal. This close association is retained throughout life, as evidenced by the intimate relations between the common bile and pancreatic ducts. The dorsal pancreas rapidly grows, elongates, and soon becomes the chief part of the organ, opening by an independent canal—the duct of Santorini—into the duodenum. The repeated division of the duct and the proliferation and extension of the terminal compartments produce the system of excretory passages and glandular tissue of the organ. The ventral pancreas, which has meanwhile increased more slowly, and in consequence of the changes in the gut has suffered displacement to the left and behind, grows towards the dorsal gland, with which it soon inseparably fuses. The head of the fully formed

organ represents the primitive ventral pancreas, the body and tail the dorsal segment. The duct of the ventral portion, which remains as the duct of Wirsung, forms a communication with that of Santorini, and for a time the pancreas possesses two outlets into the duodenum. Usually the duct of Santorini loses its intestinal connection and becomes tributary to the duct of Wirsung. Variations from this arrangement are often encountered, the different combinations being due to deviations

FIG. 1466.



Diagrammatic reconstructions, showing development of pancreas and relations to liver-ducts. *a*, common bile-duct; *b*, hepatic and *c* cystic ducts; *d*, right and *e* left ventral pancreatic anlages; *f*, dorsal pancreas and its duct (*g*); *h*, junction of common bile (*a*) and ventral pancreatic (*d*) ducts. After fusion of ventral and dorsal pancreas, *d* becomes duct of Wirsung, *g* duct of Santorini, and *i* head of pancreas.

from the ordinary progress of development as to the fusion of the two parts and persistence of their canals. The areas of Langerhans are developed from the same entoblastic outgrowths as give rise to the ordinary glandular tissue (Laguesse, Pearce[1]). The connective-tissue septa are derived from the ingrowing mesoblast.

Variations.—The pancreas has been seen to surround the descending part of the duodenum. Small accessory pancreases have been found in the walls of the intestine. Although usually in the duodenum, they may be in the stomach or at the beginning of the jejunum, and occasionally some distance from it. Presumably they are parts of the gland which became separated at an early stage and were drawn by the growth of the intestine away from their original position.[2]

PRACTICAL CONSIDERATIONS: THE PANCREAS.

Certain *abnormalities* that may affect surgical procedures or may of themselves produce symptoms of disease should be mentioned. Accessory pancreases are found in various localities and may be mistaken for new growths. The anterior wall and the two curvatures of the stomach and the walls of the small intestine, especially the duodenum, are the situations in which such glands are most frequently found. They have ducts opening into the intestine.

An accessory gland has been found to the right of the duodenum entirely distinct from the main gland. Perhaps the most important anomaly is one in which the gland completely surrounds the second part of the duodenum, constricting it and causing dilatation of the first portion and of the stomach. Several cases have been reported. The common bile-duct may also be contained within the head of the pancreas, as may the superior mesenteric vessels within its body. The accessory pancreatic duct may be absent, or there may be three ducts, all opening into the duodenum.

Movable Pancreas.—The gland may fall forward or downward (when it may sometimes be felt below the stomach), or it may be a part of the contents of a diaphragmatic hernia, or may even—but with great rarity—be contained within the sac of an umbilical hernia.

Injuries.—The situation of the pancreas behind the lesser peritoneal cavity and the stomach and between the spleen and the duodenum, the partial protection it receives from the costal arch, and the depth at which it lies render its uncompli-

[1] American Journal of Anatomy, vol. ii., 1903.
[2] Zenker: Virchow's Archiv, Bd. xxi., 1861.

cated injury of very rare occurrence. In only three fatal cases in which all other abdominal viscera escaped has it been found to be ruptured.

In less severe cases it has been bruised or torn, hemorrhage has occurred, a rapidly enlarging, fluctuating epigastric tumor has formed, and the patient has recovered after a laparotomy, evacuation of the blood-cyst, and drainage. In such cases it is probable that the traumatism has caused a laceration of the posterior layer of the lesser sac of the peritoneum (with which the pancreas is intimately adherent) and of the pancreas itself. Blood, or blood with pancreatic secretion, is poured into the lesser sac, causing adhesive peritonitis and sealing the foramen of Winslow. The lesser cavity, now converted into a closed sac, is distended with serous exudate, blood, and pancreatic fluid. After evacuation and drainage, the pancreas may continue to pour its secretion into the cyst-cavity through the original peritoneal tear (Robson and Moynihan).

Pancreatitis.—The close relation of its duct to the common bile-duct, which it often joins at the ampulla and before reaching the duodenum, explains the frequent association of gall-stones with chronic inflammation of the pancreas. A small ball-valve calculus in the ampulla has been thought, by occluding the duodenal orifice, to convert the two ducts into a continuous channel, permitting, if the gall-bladder is functionally active, the entrance of bile into the pancreatic duct (duct of Wirsung) and causing pancreatitis. A larger stone might occlude also the orifices of both the pancreatic duct and the bile-duct and produce in both glands the troubles associated with retained secretions. In the pancreas these troubles are lessened by the fact that occlusion of the main pancreatic duct does not of necessity completely obstruct the egress of the pancreatic fluid (Opie). In about 50 per cent. of bodies the accessory duct (duct of Santorini) communicates within the gland with the main duct and opens into the duodenum by a separate orifice about 2.5–3.5 cm. (1–1⅜ in.) nearer the stomach than the papilla at which the ampulla of Vater opens (Schirmer). Nevertheless, just as jaundice follows occlusion of the common bile-duct by forcing the secretion of the liver back upon that gland, whence it finds its way into the interstitial tissue, the lymphatics, the thoracic duct, the blood, and the tissues at large, so the fat-splitting ferment of the pancreatic juice, in cases of occlusion of the pancreatic duct, finds its way beyond the parenchyma of the gland and causes fat-necrosis, first in the vicinity of the pancreas, later over widespread areas (Opie).

There can, at any rate, be no question of the etiological association of gall-stones with many cases of pancreatitis; but it is probable that in a large proportion, in addition to mechanical pressure or independently of it, bacterial invasion following inflammation of the ducts or of the duodenum is an important factor.

The anatomical symptoms of *acute pancreatitis* depend upon the close association of the gland (*a*) with the solar plexus through the cœliac, superior mesenteric, and splenic plexuses; (*b*) with the duodenum; (*c*) with the bile-ducts; (*d*) with the great blood-vessels behind it; and (*e*) upon its more remote relation with the epigastric region, directly beneath which, but at a considerable depth, it lies. These relations explain (*a*) the acute and agonizing pain, vomiting, and collapse; (*b*) the intestinal paresis and distention, often simulating intestinal obstruction; (*c*) the slight but deepening jaundice sometimes present; (*d*) the cyanosis of the face and abdomen so commonly seen, and probably due partly to reflex cardiac disturbance; and (*e*) the circumscribed, tender epigastric swelling which follows closely on the above symptoms. In differentiating the condition from acute intestinal obstruction,—for which it is most likely to be mistaken,—the immediate presence of localized epigastric tenderness and the usual absence of both conspicuous general tympany and of limited distention of intestinal coils should be given due weight. The rarity in the epigastrium of an obstructed small intestine should be remembered, and the patency and capacity of the large intestine should be determined (Fitz).

Chronic obstruction of the duct may cause the development of retention-cysts, of chronic interstitial pancreatitis, or of pancreatic calculi. The latter may later become themselves the chief cause of continued obstruction and of further cystic changes.

In *chronic pancreatitis*, especially in thin patients and when the stomach and colon are empty, it may be possible to feel the tender, swollen gland through the

abdominal wall. In gastroptosis the normal pancreas may easily be felt above the stomach and might readily be mistaken for a new growth. Usually the swelling is behind the stomach and above or behind the colon. In *suppurative pancreatitis* the collection of pus may push the stomach forward, or may become superficial, either above or below it ; it may, starting at the pillar of the diaphragm, and guided by the psoas-sheath or the iliac fascia, reach the iliac region ; it may occupy the areolar tissue of the loin, becoming a perirenal abscess ; it may open into either the stomach or duodenum. When confined to the pancreas, it will usually be recognized during an exploratory operation. It may be drained posteriorly by an incision at the costo-vertebral angle, or anteriorly through a large tube surrounded by gauze packing.

Cancer of the pancreas usually affects the head of the gland, which accounts for the frequency with which obstruction of the common bile-duct and of the duodenum occurs in such cases.

The further growth of the tumor may cause compression of the pylorus, of the cardiac end of the stomach, of the whole stomach by forcing it against the anterior abdominal wall, of the colon, the ureter, the portal vein, the vena cava, the aorta, the splenic vessels, and the superior mesenteric vein (Robson and Moynihan).

If the tumor extends to the right, there are apt to be jaundice and intestinal obstruction ; if upward, in addition to these symptoms, pyloric obstruction and gastric dilatation ; if backward, ascites and œdema of the lower limbs.

The pancreas may be approached for operation through a median incision, and reached, above the stomach, through the gastro-hepatic omentum ; below the stomach, through the gastro-epiploic omentum or the transverse mesocolon, the omentum having been turned upward. It has been exposed (in a case of hydatid cyst) by an incision beginning at the tip of the twelfth rib and passing forward in the direction of the umbilicus. Indirect drainage in chronic pancreatitis by means of cholecystostomy has given excellent results (Robson).

In cases of nephrectomy the relations of its tail to the left kidney and renal vein should be remembered. The relations of the vena porta, the vena cava, the aorta, the superior mesenteric artery, and the cœliac axis are so close that when complicated by adhesions or infiltration, as in chronic inflammations or new growths, operations for total excision of the pancreas become formidable and have rarely been undertaken. The close relation of the pylorus—especially when the stomach is depressed by a new growth—to the neck of the pancreas should be remembered in pyloroplasty or pylorectomy, as should the proximity of the spleen to the other extremity of the pancreas in cases of splenectomy.

THE PERITONEUM.

The peritoneum is the serous membrane lining the abdominal cavity and reflected over the viscera. Like all serous membranes, it consists of a free mesothelial surface and a deeper layer of fibro-elastic tissue, the tunica propria. Beneath the latter a variable amount of *subperitoneal tissue* connects the peritoneum with the structures which it covers. The quantity of this areolar layer differs in various localities, and it is at times difficult to decide just what is really a part of the serous membrane proper. It is convenient to look upon the peritoneum as having a right side and a wrong side ; the former is the free mesothelial surface, the latter the areolar which is attached to other structures. Thus it may be compared to a wall-paper of a room without door or window, of which the right side is always free and the wrong side adherent to walls or to projections from them. Should a flue traverse the room, it is easy to imagine it invested by a continuation of the paper on the walls. It passes through the room, but is not within the closed sac formed by the right side of the paper. While it is true that during development the mesothelial covering grows *pari passu* with the tissue beneath it, the conception that projections of organs into the peritoneal cavity carry the serous membrane before them is very convenient and justified. The peritoneum of the female is the only serous membrane that is not a closed sac, on account of the openings of the Fallopian tubes. The blood-vessels for the viscera, around which the peritoneum is thrown, must pass on its wrong side. To return to the simile of the flue in the chamber ; if this should need

support, we can imagine it suspended in the middle by a series of cords which might be all enclosed in one fold of paper from the ceiling. This would be a *mesentery* and the cords would be blood-vessels going to the gut. The cords, of course, would be on the wrong side of the paper and the vessels on the areolar side of the membrane. A fold of peritoneum may contain large vessels and strong bundles of fibres, and at other places be no more than a duplicature of membrane. The former are the *mesenteries* and certain bands called "ligaments," the latter *plicæ* or folds. The complications of the peritoneum are reduced as much as possible by studying it in the light of development, the account of which has been already given (page 1702). Here only some of the chief points and general principles are recapitulated.

In the early fœtus the peritoneum is merely the lining of the abdomen, the *parietal peritoneum*, which covers the Wolffian bodies and the beginning of the abdominal walls, and certain median folds called *mesenteries*, conveying blood-vessels to the gut, within which certain accessory organs are developed. There is a posterior mesentery extending from the spine to the whole length of the alimentary canal below the diaphragm, to which it carries vessels from the aorta, and an anterior mesentery running to the upper part of this canal from the anterior abdominal wall (Fig. 1432). The original *posterior mesentery* is divided into three regions, each of which conveys a particular artery. 1. The mesentery of the stomach and of the duodenum, containing the cœliac axis. It is to be noted that this region may be subdivided into two parts, the upper formed by the stomach and the first part of the duodenum, the lower formed by the remainder of the duodenum. The latter originally arches forward, both ends being fixed at the spine. 2. The mesentery of the rest of the small intestine and of the ascending and the transverse colon, containing the superior mesenteric artery. 3. The mesentery of the remainder of the large intestine, containing the inferior mesenteric artery.

FIG. 1467.

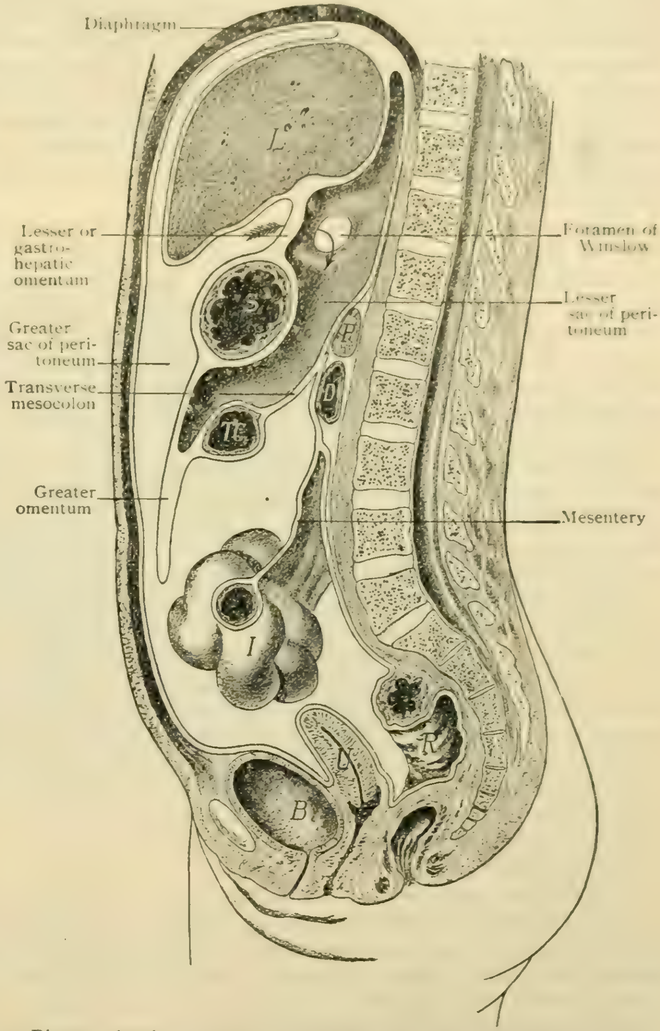


Diagram showing general arrangement of peritoneum, which is represented by the black line; arrow passes from greater into lesser sac through foramen of Winslow. *L*, liver; *S*, stomach; *P*, pancreas; *D*, duodenum; *TC*, transverse colon; *I*, small intestine; *R*, rectum; *B*, bladder; *U*, uterus.

The *anterior mesentery*, in which the liver is developed, reaches the stomach and the upper part of the duodenum, extending on the anterior wall as low as the

umbilicus (Fig. 1432). The umbilical vein runs in its free lower border to the portal fissure of the liver, whence its continuation, the ductus venosus, passes to the inferior vena cava. The anterior mesentery, containing the liver, is opposite to the *mesogastrium*, or mesentery of the stomach, which contains the spleen. The pancreas, although developed in both the anterior and the posterior mesenteries, lies chiefly in the latter. As the jejuno-ileum enlarges it hangs in loops from the spine, carrying folds of mesentery with it surrounding the vessels. The multiplication of these folds gives rise to the complication of the adult arrangement.

When two layers of a serous membrane come to lie permanently and practically immovably upon each other, there is a tendency to fusion between them, the mesothelium covering the apposed surfaces disappearing and its place being taken by connective tissue (Fig. 1472). Thus, when a mesentery lies against the abdominal wall, the mesothelium of the parietal peritoneum and of the mesentery apposed to it degenerates into connective tissue, and the peritoneum on the free surface of the mesentery becomes a part of the permanent parietal peritoneum. Much of the originally free parietal peritoneum is thus replaced by fusion with what once belonged to a mesentery.

The stomach undergoes rotation, so that the original left side becomes the anterior and the posterior border the greater curvature. The mesogastrium grows out of all proportion, so as not only to describe a curve to the left, but to hang downward in a free fold. The loop of the duodenum turns to the right, so that all of it, except the first part, lies against the posterior abdominal wall. The head of the pancreas is carried with it. The serous covering of the back of the duodenum (in its new position), that of its mesentery, and that of the back of the head of the pancreas disappear, fusing with the parietal peritoneum of the posterior abdominal wall.

The mesentery attached to the jejuno-ileum and to most of the large intestine becomes twisted as the gut returns into the abdomen from the umbilical cord, so that the cæcum is thrown upward and to the right to lie under the liver, whence it descends to its permanent place; hence the original right and left sides of the mesentery change places. The mesentery of the ascending colon fuses with the posterior covering of the right side of the abdomen; that of the descending colon to the sigmoid flexure does the same on the left.

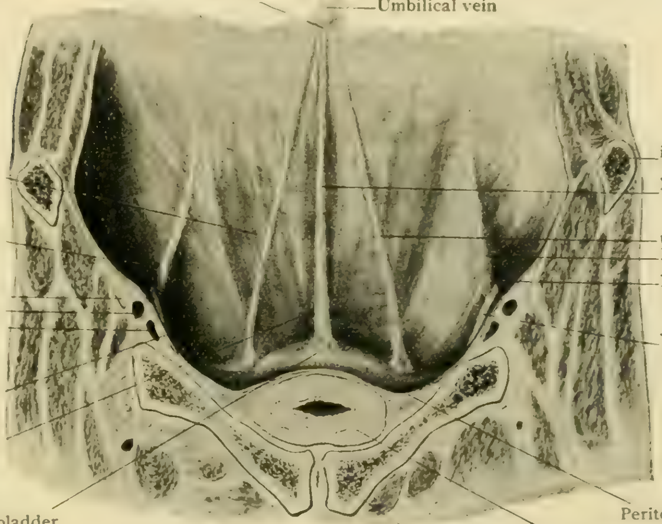
The *sub-* or *retroperitoneal tissue* is very important. As above stated, there is a thin fibro-elastic layer supporting the mesothelial cells, which is a part of the serous membrane, although it is not present in the earlier stages. Beneath this tunica propria there may be a continuous mass of connective tissue, to be compared to dense, sponge-like cobwebs, which serves as a packing between different organs and around vessels, nerves, and ducts. It may contain a large amount of fat. This is particularly developed about retroperitoneal viscera and along the aorta. The parietal peritoneum is usually thin where no fusion with another layer nor with fasciæ has occurred.

We shall describe (1) the peritoneum of the anterior and lateral abdominal walls, with its prolongations onto the diaphragm and into the pelvis; (2) the folds derived from the anterior mesentery; (3) those from the posterior mesentery from above downward. Most matters of detail are discussed with the various organs having peritoneal relations.

The Anterior Parietal Peritoneum.—Four folds diverge from the umbilicus, three running downward, symmetrically disposed,—namely, a median fold (**plica umbilicalis media**), expanding to the top of the bladder covering the *urachus*, a fibrous cord representing the atrophied intra-embryonic segment of the allantoic duct, and two lateral folds (**plicæ umbilicales laterales**) containing fibrous cords, the obliterated hypogastric arteries, continuous with the permanent superior vesical arteries. If the bladder be distended, they can be traced to its upper lateral aspects; otherwise to the sides of the pelvis. The fibrous tissue of the obliterated arteries becomes very scanty near the umbilicus. The *supravesical fossa* (**fovea supravesicalis**) or depression lies on each side above the pubes, between the median and lateral folds. On the outer side of the latter, above the middle of Poupart's ligament, is the *internal* or *median inguinal fossa* (**fovea inguinalis medialis**), which is very

distinct, and often extends inward under the obliterated hypogastric artery. Farther out a very small fold (plica epigastrica), caused by the deep epigastric artery, runs upward and inward from the external iliac artery just as the latter passes under Poupart's ligament. The *external* or *lateral inguinal fossa* (fovea inguinalis lateralis) is theoretically just external to this fold, but the fold is barely raised and a fossa not easily made out. The *internal abdominal ring* (annulus inguinalis abdominalis) is in this fossa, about 1 cm. above the middle of Poupart's ligament. A slight fold, caused by the vas deferens or the round ligament, is described as running downward from the ring into the pelvis; the fact is, however, that the structure can be only indistinctly seen through the peritoneum, and a raised fold is rare. It forms the outer border of the slightly marked *femoral depression* (fovea femoralis) opposite the *femoral ring* (annulus cruralis), between the pubes and Poupart's ligament. The peritoneum is continued laterally on either side without presenting any feature that calls for description until it reaches the ascending or the descending colon. All the serous covering anterior to these structures is derived from the parietal peritoneum; that posterior to them is derived from the mesenteries of the colons which

FIG. 1468.



Frontal section of formalin subject, showing posterior aspect of abdominal wall, covered with peritoneum.

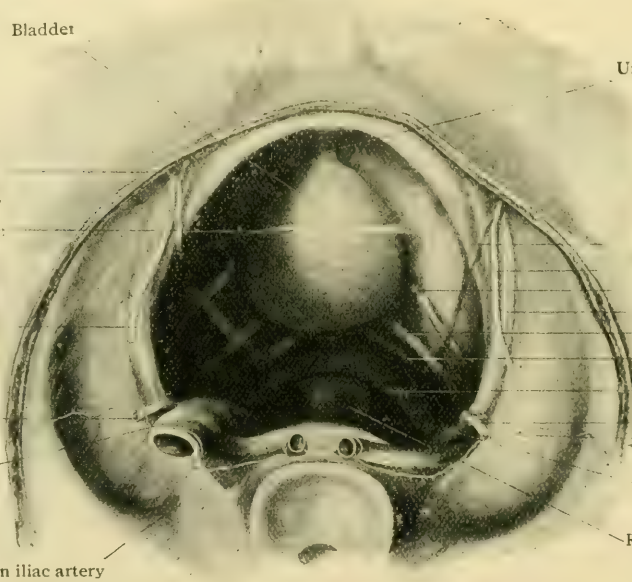
have fallen over onto the posterior abdominal walls. It will be considered later. The parietal peritoneum is also to be traced onto the under surface of the diaphragm until far back it meets the folds derived from the mesenteries. On either side of the bundle of fibres arising from the ensiform cartilage there is an interruption in the muscle of the diaphragm, where only areolar tissue separates the peritoneum and the pleura or pericardium.

The parietal peritoneum is continued into the pelvis, where it meets the mesentery of the colon and is continued over the bladder, and in the female over the uterus and Fallopian tubes. Nowhere is the comparison to a wall-paper so apt as here, where the peritoneum can be traced from the walls over the inequalities formed by the upper surfaces of the pelvic organs. The depression between the bladder and the rectum in the male, the *recto-vesical pouch* (excavatio recto-vesicalis), in the female is subdivided into the *utero-vesical pouch* (excavatio utero-vesicalis) and the *recto-uterine pouch* (excavatio recto-uterina). The latter and deeper, also known as the *pouch of Douglas* (cavum Douglasi), is bounded laterally by the *utero-sacral folds* (plicæ recto-uterinæ), which pass from the lower part of the uterus backward

and outward to the side of the rectum and the pelvic wall. The peritoneal fold investing the uterus extends laterally on either side as the broad ligament (**ligamentum latum**) to blend with the parietal peritoneum covering the sides of the pelvis. Below, the broad ligament is attached to the pelvic floor, its superior margin being the free edge of the fold. On either side of the rectum, between the gut and the wall of the pelvis, lies the *pararectal fossa*, the size of which varies with the distention of the intestine. The special features of the peritoneum are described with the rectum (page 1679) and with the uro-genital system (page 1905).

The arrangement over the anterior half of the lateral wall of the true pelvis is different according to sex, since in the female there is the line of attachment of the broad ligament of the uterus and the fossa for the ovary. Otherwise the features are about the same, the vas deferens of the male and the round ligament of the female causing similar folds. These structures run backward from the internal ring along the wall of the pelvis, turn down to the side of the bladder, and bound externally and posteriorly the *paravesical fossa* between the pelvic wall and the

FIG. 1469.



Pelvic peritoneum from above and behind, showing folds and fossæ.

bladder when the latter is not distended. A transverse fold of peritoneum, *plica vesicalis transversa*,[1] passes laterally from the upper surface of the empty bladder and subdivides the paravesical fossa into an anterior and a posterior compartment. The vas deferens, or round ligament, forms (the body being upright) the lower side of the *obturator triangle*, which is completed in front by the external iliac vein and behind by the ureter, which crosses the external iliac vein at the apex. The obturator vessels and nerve lie in the floor of this triangle. In the female it is crossed by the lateral attachment of the broad ligament of the uterus, behind which is the fossa for the ovary (**fossa ovarica**).

The Anterior Mesentery.—This originally extended from the anterior abdominal wall to the lesser curvature of the stomach and to the beginning of the duodenum. It is subdivided into two portions by the liver, which develops within it. The anterior part is the falciform ligament, between the abdominal wall and the liver; the posterior part is the gastro-hepatic omentum, between the liver and the stomach.

[1] Waldeyer: Journal of Anatomy and Physiology, vol. xxxii., 1898.

The *falciform ligament* (ligamentum falciforme hepatis) makes the fourth fold which has been mentioned as leaving the umbilicus. Seen from the side, it is a sickle-shaped fold attached to the anterior wall above the umbilicus and later to the diaphragm as far back as the top of the fissure of the ductus venosus on the posterior surface of the liver (Fig. 1441). In its free inferior border runs the round ligament, once the umbilical vein, from the umbilicus to the notch in the liver, and thence in its own fissure on the under surface until it reaches the portal fissure, where the falciform ligament ends. The latter divides the upper part of the dome of the abdomen into two chambers, one on either side, of which the left one is the larger. There is but little areolar tissue in the folds of the falciform ligament. Small veins run along the round ligament, connecting the hepatic system with that of the abdominal walls. Although in the embryo the fold starts from the navel, in the adult it does not leave the abdominal wall for an inch or more above it.

The superior surface of the liver is covered with peritoneum from either side of the falciform ligament, which at the top of the posterior surface is reflected onto the under side of the diaphragm. At the edge of the right lobe, which has a considerable posterior surface uncovered by peritoneum and attached to the diaphragm, the layers covering the upper and lower surfaces meet to form the *right triangular ligament*, which is attached for a short distance beyond the liver to the diaphragm and has a sharp, free edge. There is a similar arrangement on the upper surface of the left lobe, but the *left triangular ligament* is longer, and passes to the diaphragm on the left of the œsophageal opening and above the spleen. Passing around the border of the right lobe of the liver, the peritoneum spreads over the inferior surface of that lobe as well as of the quadrate covering the gall-bladder which lies in a hollow between them. Exceptionally the gall-bladder is entirely surrounded, and is attached to the liver merely by a narrow fold. The peritoneum is continued over the cystic duct to the edge of the lesser omentum, to be presently described. The entire under surface of the left lobe is also covered by peritoneum continuous with the preceding. The passage of the finger on this surface to the right is interrupted at the front by the end of the falciform ligament between it and the quadrate lobe. At the back farther progress to the right is stopped by the lesser omentum in the fissure of the ductus venosus. All the peritoneal covering of the liver has thus been accounted for, excepting that of the caudate lobe and of the lobe of Spigelius.

FIG. 1470.

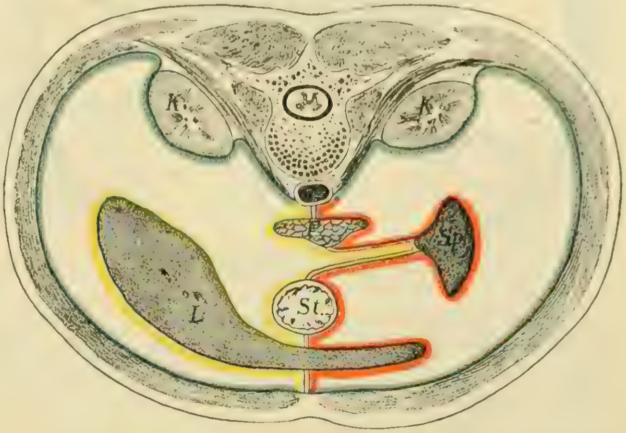


Diagram showing early arrangement of parietal and visceral peritoneum. Blue, parietal; yellow, right side, red, left side of visceral. *L*, liver; *St*, stomach; *Sp*, spleen; *P*, pancreas; *K*, kidney.

The *gastro-hepatic* or *lesser omentum* (ligamentum hepatogastrium, omentum minus) is that part of the original anterior mesentery connecting the stomach and the beginning of the duodenum with the liver. It must, theoretically, have been originally a median antero-posterior fold, but it is now so twisted in consequence of the change in position of the stomach as to be chiefly nearly transverse. Its line of attachment to the stomach is along the lesser curvature from the gullet past the pylorus, continued onto the first part of the duodenum, where it crosses from the top to the left of the gut, until it passes the common bile-duct (by which the ducts of the liver originally grew out of the gut) with its companions, the hepatic artery and the portal vein. It is formed by the union of the peritoneal layers covering respectively the front and back of the stomach and the sides of the duodenum con-

tinuous with them. The two layers join at the bundle of vessels just mentioned. thus forming a fold which is the termination of the lesser omentum on the right, known as the *duodeno-hepatic omentum* (**ligamentum hepatoduodenale**). The lesser omentum is sometimes described as prolonged across the first part of the duodenum to the transverse colon, fusing with the greater omentum. This is only an accidental modification, although a very common one. An accessory fold, the *duodeno-cystic ligament*, is prolonged to the right from the front of the lesser omentum, around the cystic duct from the gall-bladder. The hepatic attachment of the lesser omentum is to the transverse fissure of the liver and from its left end to the fissure of the ductus venosus. From the point at which the latter reaches the diaphragm the two layers diverge, the left one passing to the lower side of the left lobe and the right one to the lobe of Spigelius. The structure of the lesser omentum is dense and fibrous at the right. It is very delicate in the middle, but somewhat thicker at the left end. The fold around the vessels at the free edge (Fig. 1473) forms the anterior border of the *foramen of Winslow* (**foramen epiploicum**), a narrow part of the peritoneal cavity by which the general cavity communicates with that behind the stomach which has been formed by the rotation of that organ and the inordinate growth of the mesogastrium. The foramen is circular, with a diameter of from 2–3 cm. Of the three vessels in the fold forming its *anterior border*, the portal vein is the posterior at the point of entrance into the liver, with the hepatic artery in front on the left and the hepatic duct in front on the right. The cystic duct is really in an accessory fold. The hepatic artery, which passes along the left side of the duodenum and turns upward, is the vessel that most definitely bounds the foramen in front. The duodenum lies below the foramen, but its *lower border* is often formed, not by the gut, but by a fold of serous membrane arising from it. The foramen is bounded *behind* by the vena cava and *above* by the caudate lobe of the liver, which is covered by peritoneum.

Fig. 1471.

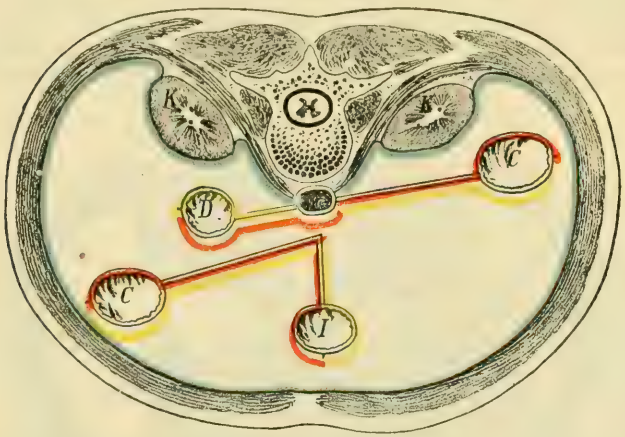


Diagram showing changed relation of visceral peritoneum in consequence of twisting, so that original right and left sides of mesentery of small intestine and of part of colon have exchanged places. The detached portion which is twisted is supposed to be attached at a higher level. *D*, duodenum; *C*, *C*, ascending and descending colon; *I*, small intestine; *K*, kidney; *D*, *C*, *C* are being displaced towards posterior wall.

The Posterior Mesentery: Part I.—The posterior mesentery arises from the spine, with the aorta between its folds. The first part is the *mesogastrium*, in which run the branches of the cœliac axis. It will be remembered that, except at the fundus, this is attached to the greater curvature of the stomach, which was originally the posterior border, but which has turned to the left. The spleen and most of the pancreas are developed in this fold, which grows inordinately. We must trace it both in a horizontal and in a sagittal plane. To understand the horizontal arrangement, it is sufficient to remember that the original mesentery, which ran straight forward from the spine to the stomach, in its subsequent excessive growth describes a loop to the left (Fig. 1470), so that the original left side of the mesentery near its root faces backward, and later, after the bend of the loop, forward, ultimately covering the anterior wall of the stomach. This fold forms a great pouch behind and below the stomach called the *lesser cavity of the peritoneum* (**bursa omentalis**), which, of course, is continuous with the general cavity. The mesothelium of the left side of the mesentery nearly to the spleen fuses with that of the posterior wall of the abdomen, so that the splenic vessels and the pancreas which are in it come to lie behind the per-

manent serous covering of the posterior abdominal wall, which here is that of the original right side of the mesogastrium. The spleen, and perhaps the tail of the pancreas, lie free, surrounded by peritoneum. If the hand be introduced into the left hypochondrium, it slides along the wall behind the spleen to the point at which the splenic vessels leave the posterior wall and pass in a fold, the *lieno-renal ligament*, to the hilum of the spleen. From this position the hand can be carried around the spleen to the front of the vessels at the hilum and thence to the right along the continuation of the mesogastrium to the greater curvature of the stomach, where its layers separate to coat the front and back of that organ. The part of the mesogastrium between the stomach and the spleen is the *gastro-splenic omentum*. The right layer of peritoneum of the mesogastrium, lining first the hind wall of the abdomen and then the back of the stomach, bounds the lesser cavity of the peritoneum. The *gastro-phrenic ligament* is a small vertical fold, usually found extending from the left of the end of the œsophagus to the top of the stomach. Near it is often another, the *suspensory ligament of the spleen*, extending from the diaphragm to the top of that organ, of which it may enclose a small part. It marks the upper part of the line of reflection of the mesogastrium from the posterior abdominal wall. The *phreno-colic fold*, also derived from the mesogastrium, is a horizontal shelf with a free anterior semilunar edge forming the floor of a niche for the spleen. It extends from about the eleventh rib inward onto the upper surface of the transverse colon. That this ligament is really a part of the mesogastrium, and not a ligament of the colon, is shown by development, as well by its existence (as in the monkey) when the descending colon is unattached to the wall.

FIG. 1472.

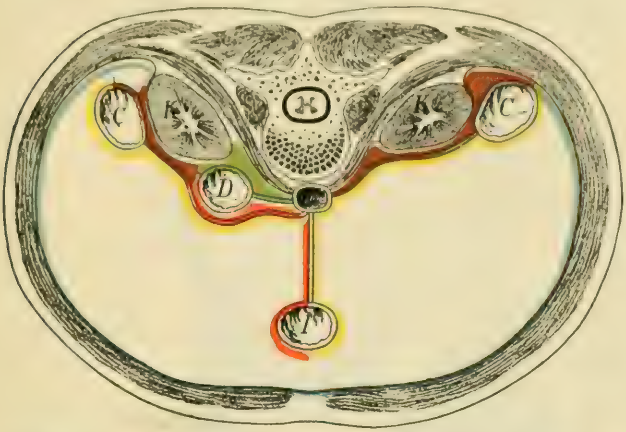
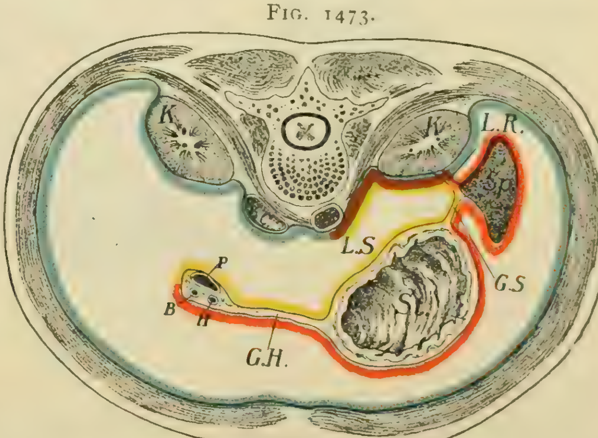


Diagram showing later stage where secondary mesentery is formed and duodenum (D) and colons (C, C) lie against posterior body-wall. The additional colors indicate the fusion of the original parietal and visceral peritoneum, purple from the blue with the red, green from the blue with the yellow.

FIG. 1473.

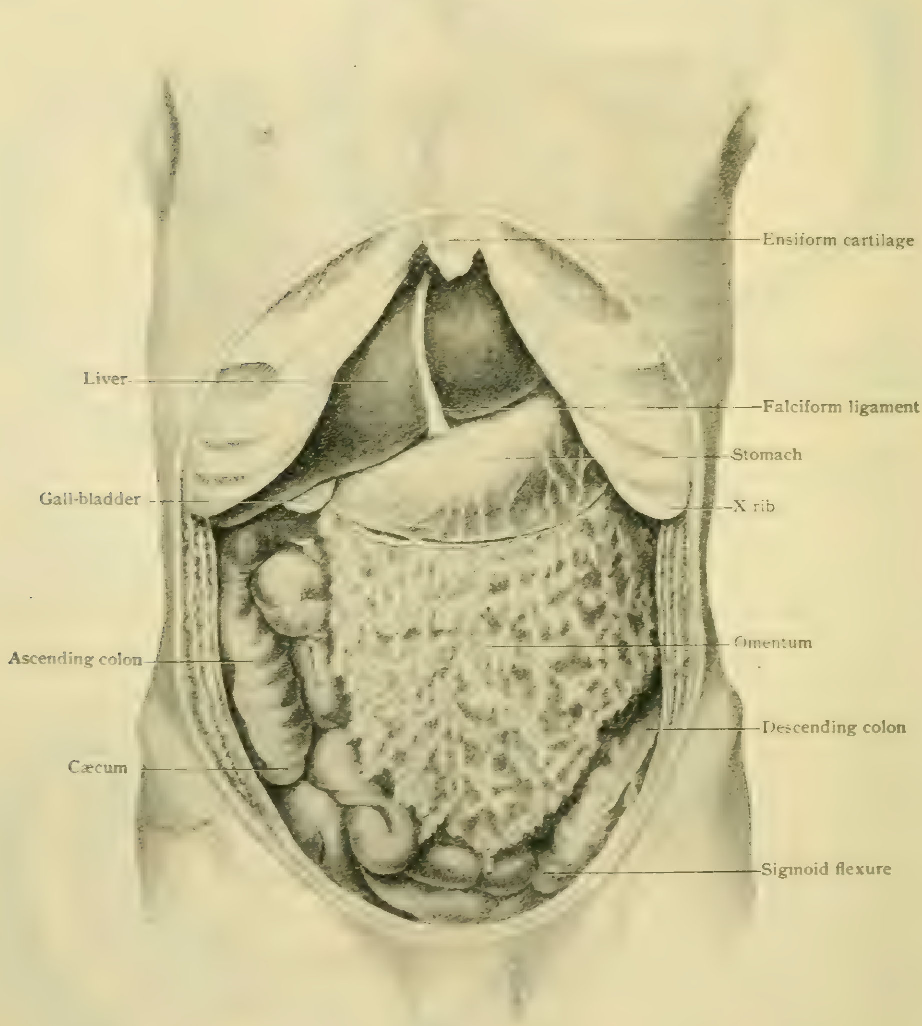


Diagrammatic section passing through level of foramen of Winslow, showing relations of parietal and visceral peritoneum within lesser sac (LS); GH, cut gastro-hepatic omentum, containing portal vein (P), hepatic artery (H), and bile-duct (B); St, stomach; GS, gastro-splenic omentum; LR, lieno-renal ligament; VC, A, vena cava and aorta.

The Greater Omentum.—We are now to trace the mesogastrium in a sagittal plane downward from the greater curvature of the stomach. On opening the abdomen the first thing that appears below the stomach is the *greater omentum* (**omentum majus**), which is spread like an apron over the intestines. It is that part of the mesogastrium which is situated in front. The terms *gastro-colic* and *gastro-splenic omenta* are but names for different parts of this structure. It extends from the greater

curvature of the stomach, where it is continuous on the left with the double layer coming from the spleen and on the right with that coming from the inferior surface of the first part of the duodenum ; from this broad origin the greater omentum hangs down over the intestines to near the pubes, where it turns upon itself and ascends posteriorly. Often it does not descend so far, but may be folded upon itself to almost any degree and in almost any position. For purposes of description it is supposed to lie spread out smoothly, and to consist of an anterior and a pos-

FIG. 1474.



Undisturbed abdominal viscera of formalin subject; liver and stomach abnormally large, hence the exaggerated apparent transverse position of stomach.

terior fold (Fig. 1467). The former passes down over the transverse colon, but without adhering to it. The peritoneum on its anterior surface faces forward into the greater peritoneal cavity, while that on its posterior surface looks into the lesser one. On turning backward upon itself, it runs up to the transverse colon. If this were literally true, it is evident that the lesser cavity would extend from behind the stomach over the colon down into this fold (**recessus inferior omentalis**) of the greater omentum, and in fact this is actually the case in the fœtus (Fig. 1439) and exceptionally

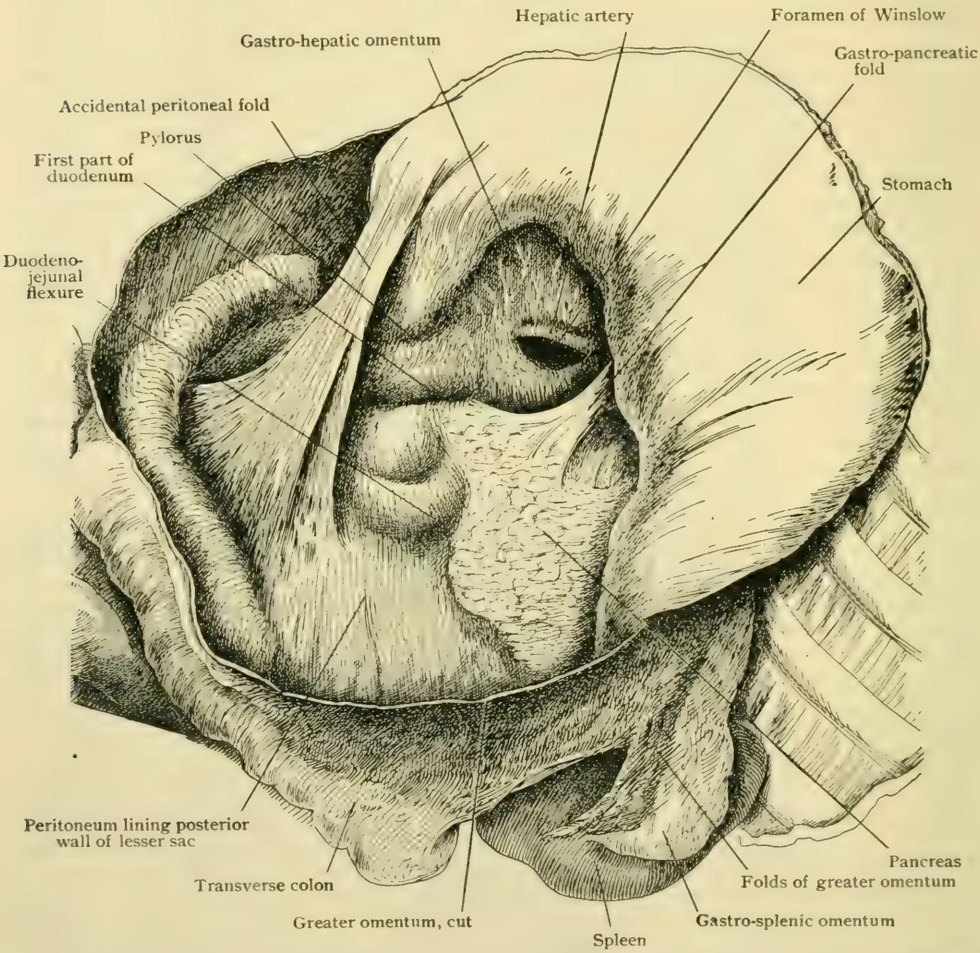
in the adult; but generally, except just below the colon, the two layers fuse into one. In the adult, when the returning fold reaches the transverse colon, the two layers composing it seem to diverge to enclose the intestine, and, reuniting above it, to be continued upward as the transverse mesocolon to a line running across the back of the abdomen, to be described later. This is an extraordinary and apparently contradictory arrangement by which a part of the mesogastrium, or mesentery of the stomach, has become also the mesentery of a part of the colon. The explanation is furnished by embryology, since the original arrangement is very different. In the fœtus (Fig. 1439) the returning fold of the greater omentum passes up in front of the colon to the posterior wall along the lower border of the pancreas. The posterior layer of the greater omentum is in fact the left layer of the original mesogastrium, which we should be able to follow to the aorta, had it not, with the pancreas, become adherent to the posterior wall. It has no connection whatever with the transverse mesocolon; it simply lies upon it. At about birth, however, the two apposed layers begin to fuse. The acquired line of attachment to the transverse colon is low on the right and high on the left. Sometimes near the spleen it joins, not the colon, but the mesocolon above it.

The Structure of the Greater Omentum.—There is hardly any framework apart from the vessels that course through it, save a most delicate layer of fibro-elastic tissue which supports the mesothelium. In the adult more or less fat is found about the vessels, and in some cases the omentum is loaded with it. The two layers of serous membrane are sometimes beautifully distinct; in other cases no trace of a double origin can be recognized. Sometimes parts of the omentum atrophy and disappear, leaving windows, or *fenestræ*, between the meshes of the vessels. The arteries are long and very slender. They arise from the gastro-epiploic arteries at the greater curvature of the stomach and run straight downward to the folded border of the omentum, and then up again in the posterior fold, to anastomose with the arteries of the colon. In their course they send off small side branches which meet those from the next branch. The arrangement of the veins is essentially the same.

The Lesser Cavity of the Peritoneum.—The mesogastrium, starting at the aorta, takes a great turn to the left, and its first part, containing the pancreas, fuses with the posterior abdominal wall. This fold is only a part of a great pouch that runs downward also. If examined before it has become adherent to the transverse mesocolon, its continuation from below the pancreas is to be followed down over the colon as the posterior layer of the greater omentum. In the description of the folds of the adult in a sagittal plane it was necessary, on account of this adhesion, to reverse the normal course and to follow it from its insertion into the stomach back to its origin. If a cut be made through the greater omentum between the stomach and the transverse colon, the *lesser sac* (**bursa omentalis**) is opened so that its posterior wall can be examined (Fig. 1475). This is seen covering the pancreas, the splenic vessels and the posterior abdominal wall, part of the spleen, part of the left kidney, and the left suprarenal capsule. At the right is the foramen of Winslow, which is generally, but inaccurately, considered the communication between the greater and lesser cavities. It cannot be the true entrance into the lesser cavity, because, owing to the median arrangement of the original mesentery, this opening cannot be on the right of the median line. The real communication between the two cavities is somewhat contracted (**isthmus bursæ omentalis**) and indicated by the median vertical fold—*plica gastro-pancreatica*—made by the mesogastrium over the gastric artery of the stomach as it arises from the cœliac axis to the cardia. On the left of this fold is the lesser cavity proper; on the right of it, extending to the foramen of Winslow, is a small cavity,—the *vestibule* (**vestibulum bursæ omentalis**),—bounded behind by the original parietal peritoneum of the right abdominal wall and extending upward behind the lobe of Spigelius (Fig. 1476). The sides of the pocket behind the liver (**recessus superior**) are the reflections of the peritoneum over the left of the inferior vena cava and the right of the ductus venosus, which meet above, roofing it in. The first part of the duodenum, which forms the lower boundary of the foramen of Winslow, passes backward and upward, so that the loop of intestine, which the duodenum originally formed, must be considered as having fallen

over onto the right side against the right of the spinal column, to the peritoneal covering of which it has grown with the transformation into connective tissue of the right serous covering of its mesentery. The second or descending portion of the duodenum lies against the right of the column under the permanent parietal peritoneum, derived from the mesocolon, as is shown later. The great difficulty of understanding the lesser cavity is that in man the duodenum rises to so near the liver that the entrance to the vestibule at the foramen of Winslow is very small. If, as in many animals, these parts were more distant, it would be evident that this is a pouch-

FIG. 1475.

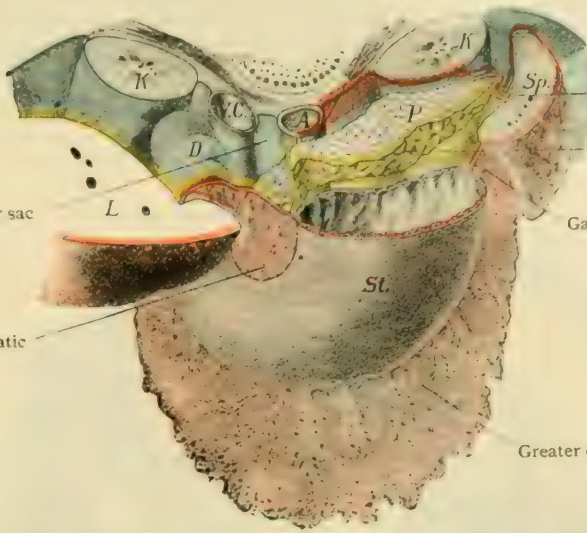


The subject, lying on its back, is seen from the left side; the stomach, except fundus, is turned over. The greater omentum has been cut below the greater curvature of the stomach so as to open the lesser sac to show the foramen of Winslow from the left side.

like formation, the mouth of which is behind the edge of the lesser omentum. The relations to the mesogastrium of three branches of its artery, the cœliac axis, are as follows. The splenic artery, in the adult condition, lies entirely behind the permanent peritoneum to near the hilum of the spleen, where the mesogastrium is no longer attached to the wall. It then sends its terminal branches to the spleen, the gastro-epiploica sinistra to the greater curvature of the stomach, and the vasa brevia to the fundus. The gastric artery, originally in the mesentery of the duodenum, reaches the cardiac end of the stomach through the *plica gastro-pancreatica*, and then runs between the layers of the lesser omentum along the lesser curvature.

The hepatic artery reaches the duodenum through its mesentery, and crosses the left side of the gut, to which it gives branches. Thence it runs in or near the edge of the lesser omentum at the foramen of Winslow to the portal fissure.

FIG. 1476.

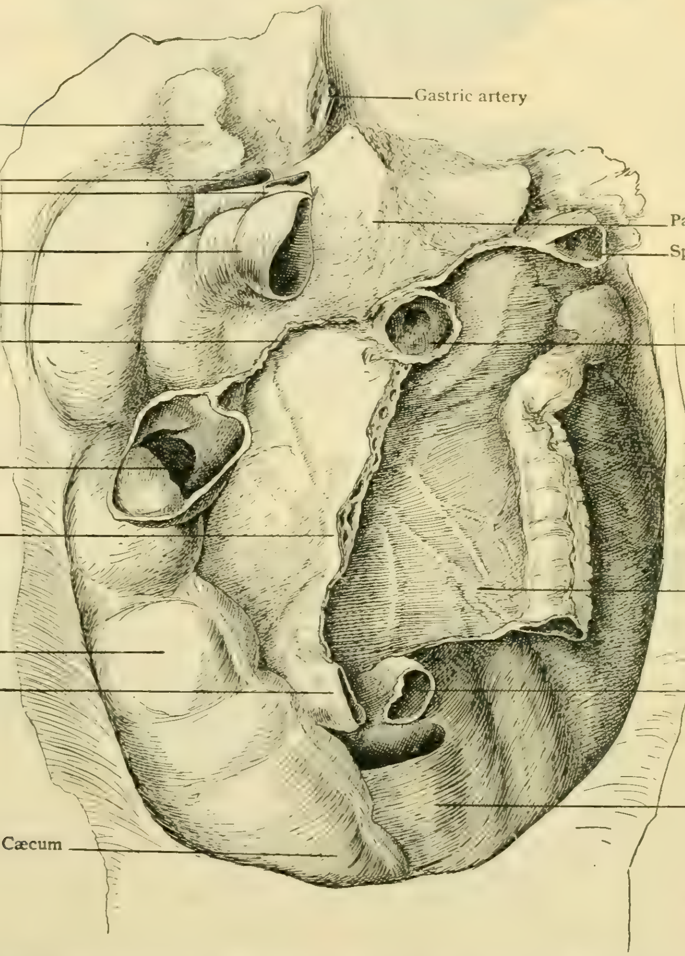


Schematic reconstruction, showing relations of peritoneal layers in vicinity of lesser sac. Upper surface of duodenum (*D*) at floor of foramen of Winslow lies at deeper level than plane of section. It is to be noted that only that part of peritoneum covering posterior wall of lesser sac is derived from greater omentum which lies to left of aorta, beginning at gastro-pancreatic fold. *L*, liver; *St*, stomach; *Sp*, spleen; *P*, pancreas; *K*, kidney.

The Posterior Mesentery: Part II.—This is that part of the peritoneum derived from the original mesentery of the jejuno-ileum, the cæcum, and the ascending and transverse colon. Its artery is the superior mesenteric. If the transverse colon with the greater omentum be turned upward and the small intestine to the right, the left side of the mesentery of the jejuno-ileum is seen running from the left of the top of the body of the second lumbar vertebra to the right sacro-iliac joint. At the beginning this is attached to the lower side of the gut, where it makes a sharp flexure at the origin of the jejunum from the end of the duodenum. This flexure lies directly in front of the aorta, which usually lies covered with peritoneum at the back of the abdomen, with the fourth part of the duodenum to the right of it. (This relation is more fully described with the duodenum (page 1647). The line of attachment of the mesentery (Fig. 1477) descends over the fourth part of the duodenum, crossing the third part and the inferior vena cava. The greatest breadth of the mesentery to the free border is from 20–23 cm. (8–9 in.). It reaches its full breadth almost at once after its origin. Usually it becomes very narrow—perhaps only 12 mm.—at its termination; but this varies much, as does also the point of that termination. The connective tissue between the layers is thickest and the lymph-nodes most numerous near the attached part. Except in very fat subjects, there is little between the layers of peritoneum besides the vessels, within an inch or so of the gut. The superior mesenteric artery can be felt at the top, entering it from under the lower border of the pancreas. The peritoneum can be followed at any point across from the left to the right side of the mesentery. From the latter it is followed along the posterior wall to the kidney and the ascending colon, lying on the front of the latter, where they are in contact. The membrane crosses the ascending colon, leaving its posterior surface without covering attached to the parts behind it, and completely envelops the cæcum, passing on the left into the mesentery. Very often the peritoneum is carried for an inch or two behind the lower part of the ascending colon. It then passes into the left flank and the pelvis without incident. Development shows that this is a departure from the original condition, in which the

attachment of this mesentery was exceedingly short, merely broad enough to contain the superior mesenteric artery. The so-called *permanent mesentery* is caused by the falling over to the right of the fold of mesentery for the ascending colon, twisting the membrane, and the downward growth of that part of the gut which brings the cæcum down from under the liver to the right iliac fossa. The twist having occurred, and the ascending colon having fallen against the abdominal wall, the fold bearing the ascending and transverse colon becomes fused with the peritoneum of the posterior right abdominal wall on the right of a line from the beginning of the jejunum

FIG. 1477.



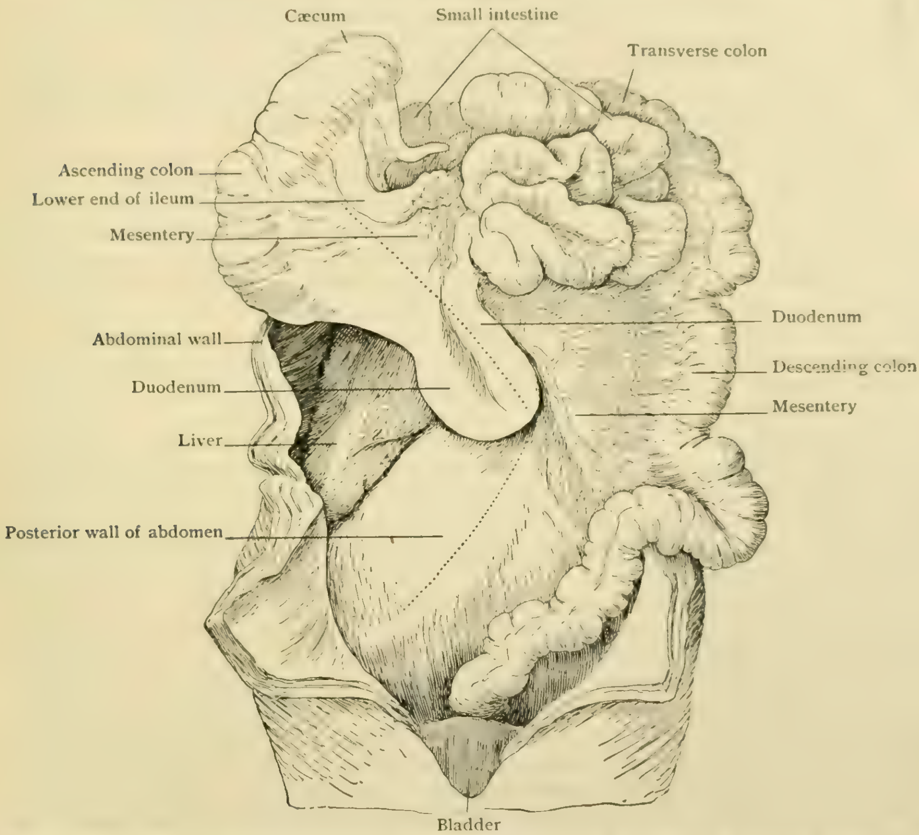
Showing relations and attachments of mesentery of small and large intestines; greater part of transverse colon, of sigmoid flexure and of jejuno-ileum has been removed, the latter by cutting through the mesentery near its posterior attachment.

to the end of the ileum, the part bearing the small intestine remaining free. This oblique line of attachment becomes the permanent mesentery. The peritoneum to the right of it, as far as the ascending colon, forms the permanent parietal peritoneum, having fused with the original parietal layer behind it. When the colon under the liver becomes the transverse, the part nearest to the latter continues free and hangs down as a transverse fold, on which the greater omentum lies, and subsequently fuses, as already described. The transverse colon is attached by the transverse mesocolon (also a secondary adhesion) to the front of the right kidney and to the posterior wall across the second part of the duodenum and the head of

the pancreas along the lower border of that gland to the left kidney (Fig. 1477). Its greatest breadth is some five or six inches. (For a fuller description, see peritoneal relations of the colon, page 1670.) The breadth of the transverse mesocolon is from 12–15 cm. (5–6 in.). In the adult it is fused with the greater omentum, as already described. The superior mesenteric artery enters this mesentery under the pancreas, and gives from its left or convex side the branches for the small intestine. From its right, just after its origin, it gives off the inferior pancreatico-duodenal and the branches for the cæcum and the ascending and transverse colon. In the adult the right colic artery runs behind the permanent posterior parietal peritoneum.

The Posterior Mesentery: Part III.—The region of the inferior mesenteric artery is very simple. Starting at the left of the permanent mesentery of the small intestine, the peritoneum is traced over the posterior abdominal wall, over

Fig. 1478.



Mesenterium commune in child of three years; the usual relations would be restored by bringing upper dotted line in contact with lower.

the lower part of the left kidney, and over the descending colon, which, although touching that organ, lies chiefly external to it. The posterior surface of the gut is retroperitoneal. The descending colon has fallen over to the left, so that the peritoneum of the left side of its mesentery has fused with that of the abdominal wall, and the permanent serous covering of the posterior wall is derived from that of the right side of the original mesentery. This fusion ceases at the crest of the ilium, and the sigmoid flexure retains at least a part of the original mesentery (Fig. 1478). The line of its attachment runs in more than one direction, according to the amount of freedom of the fold, from that point to the middle of the third sacral vertebra. (The chief forms are described on page 1671.) Beyond the latter level the rectum is partly uncovered behind, where the mesentery ceases, and its gradually diverging

lines pass onto its sides, leaving the termination of the gut without any peritoneal covering. The branches of the inferior mesenteric artery in this region are the left colica sinistra, which runs behind the permanent parietal peritoneum ; the sigmoid, which does the same until it reaches the part of the mesentery which is free ; and the superior hemorrhoidals, which descend in the lower part of the original mesentery until they reach the retroperitoneal area behind the rectum.

PRACTICAL CONSIDERATIONS : THE PERITONEUM.

The development, topography, and relations of the peritoneum have already been sufficiently described. It remains to consider its diseased conditions and those in which it is an important or controlling factor in the production of disease in so far as they are influenced by anatomical circumstances.

Peritonitis is the most common and the most serious of peritoneal diseases. The separate consideration of *wounds* of the peritoneum is not necessary, as traumatism, unassociated with infection, produces merely hyperæmia and exudation. The process is for convenience known as plastic or reparative peritonitis, a term also applied to those forms of true (infective) peritonitis in which the bactericidal and absorptive powers of the membrane itself and of its serum have resulted in the destruction or the isolation of the invading bacteria.

The anatomical routes by which bacteria may reach the peritoneum are :

1. From without, as through an accidental or operative wound.
2. From within, as from an escape of the micro-organisms through intestinal walls leaky as a result of strangulation (as in intestinal hernias or volvulus or intussusception) or of inflammation (as in appendicitis) ; or through an actual perforation, as in gastric ulcer, typhoid fever, or intestinal cancer.
3. Through the blood- or lymph-channels, as in many cases of tuberculous peritonitis and possibly in so-called rheumatic, nephritic, and other clinical forms of peritonitis, in some of which the infecting organism is still unknown.
4. Through the Fallopian tubes.

The peritoneum is not equally susceptible to traumatism or to infection on both its surfaces or in all its parts. The external, areolar, or "wrong" side (page 1740) may be extensively separated from the subjacent structures (as in the extraperitoneal approach to the ureter or to the common iliac artery), or may be in contact for a long time with an inflamed or a suppurating surface (as in perirenal or other retroperitoneal abscess) without damage to the mesothelial or free surface of the membrane, and with but little risk of the supervention of peritonitis.

On the other hand, a small penetrating wound made with a dirty instrument will probably set up a diffuse and perhaps a fatal inflammation.

The difference in results is due to the delicacy and vulnerability of the mesothelial as compared with the fibrous surface ; to the great absorbent power of the former (*vide infra*), the area of which is about equal to that of the cutaneous surface of the body, favoring toxæmia if the bacteria and their toxins are not destroyed or encapsulated ; to the excellent culture material supplied by blood-clot or by the injured or necrotic epithelial surface ; and to the involvement in diffuse or spreading cases of the peritoneal covering of the neighboring viscera, particularly the intestines.

These facts determine the surgical rule that in doubtful cases of bullet and stab wounds of the abdominal wall it is well—under aseptic conditions—to enlarge the wound, ascertain the presence or absence of penetration, and cleanse or drain if necessary.

Not only are the two sides of the peritoneum thus unlike in susceptibility to infection, but a similar difference exists between the parietal peritoneum and that covering the viscera. The former, applied by a layer of fat-containing connective tissue to the relatively immobile muscular layer of the abdominal wall, is less easily inflamed, or if inflamed develops a less diffused and less quickly spreading form of peritonitis than does the thinner, more sensitive, and more vulnerable visceral peritoneum, especially that covering the most mobile of the abdominal viscera, the small intestine.

So, too, peritonitis originating in certain regions is, by reason of the facility with which they may be shut off by adhesions, less threatening in its course and

more amenable to surgical treatment than that beginning elsewhere. Pelvic peritonitis, para-appendical and paracolic peritonitis, subdiaphragmatic and subhepatic peritonitis, and peritonitis limited to the lesser peritoneal sac (*vide infra*) are all varieties that are less dangerous than is peritonitis beginning among the shifting coils of small intestine.

The anatomical sources of peritoneal infection may therefore be arranged approximately in the order of their gravity, as follows: (*a*) perforations or wounds of the small intestine; (*b*) perforations or wounds of the stomach or large intestine; (*c*) perforations or wounds of other viscera, including kidneys, ureters, bladder, pancreas, and bile-passages; (*d*) entrance of bacteria by continuous growth through inflamed gastro-intestinal walls; (*e*) bacterial migration through strangulated intestine; (*f*) infection through the Fallopian tubes; (*g*) wounds of the abdominal wall (Fowler).

This arrangement is based upon two factors: the number and virulence of the bacteria which are likely to gain entrance, and the opportunity which will probably be afforded for the formation of limiting adhesions. The latter factor should be considered from the anatomical stand-point, as the variations in the intensity of the inflammation due to varying forms and doses of the invading bacteria are influenced by the site of a wound or other traumatism, or of an ulcerative or necrotic process in the abdominal viscera. For example, and for reasons already indicated, penetrating wounds above the level of the umbilicus are less likely to produce fatal peritonitis than are those in the lower half of the abdomen. The differences in this respect between wounds or perforations of the stomach, of the different portions of the small intestine, and of the large intestine have been described in relation to the anatomy of those portions of the gastro-intestinal tract.

The resistance of the peritoneum to infection is usually in direct proportion to the normality of its mesothelial coat, which is lessened by all forms of traumatism, including handling or sponging, or irrigation with strong antiseptics. To a certain extent the sensitiveness of the peritoneum and the rapidity with which it responds to irritation is a conservative process. The prompt exudation which follows either injury or infection often isolates the affected area and prevents a fatal diffusion of inflammation. The great absorptive power of the peritoneum—which should be studied also in connection with the lymphatic system—may be alluded to here, as it aids materially in lessening the danger from infection. It has been demonstrated experimentally that from 3 to 8 per cent. of the body weight in fluid can be taken up by the peritoneum from within its cavity in one hour, which is equivalent to the total body weight in twenty-four hours (Wegner). The current of this process of absorption of peritoneal serum has been shown to set normally from the peritoneal cavity towards the diaphragm, and to be much hastened by elevation of the pelvis and lower abdomen. Small particles (carmine, bacteria, etc.) are carried through the intercellular spaces in the diaphragmatic peritoneum—"the openings made by the retraction of the endothelium" (Kelly)—into the lymph-spaces beneath, then into the mediastinal lymph-spaces and glands, and then into the blood-current (Muscatello). This process goes on much more rapidly in this direction—towards the diaphragm and mediastinal glands—than does the similar process beginning in the visceral (intestinal) peritoneum and associated with the mesenteric lymph-nodes,—an additional anatomical explanation of the greater fatality of visceral peritonitis.

The close relation of the nerves of the peritoneum and of the abdominal viscera to the nerves supplying the abdominal and the lower intercostal muscles has been mentioned in relation to appendicitis and other intra-abdominal lesions (pages, 528, 1683), and is of the highest importance in connection with the clinical symptoms of peritonitis. Hilton compares the peritoneum and the muscles of the abdomen to the synovial membrane and the muscles moving a joint. The rigidity that follows inflammation in either case is due to the reflex muscular spasm resulting from the correlation of the nerve-supply. Thus the six lower intercostals supplying the corresponding intercostal muscles and passing through the diaphragm, to which they send twigs, are distributed to the skin over most of the abdomen, and to the rectus, external and internal oblique, and transversalis muscles. Through the splanchnics they join also in the innervation of the peritoneum and of the abdominal viscera. In

a case of injury to the abdominal wall, therefore, the impression is barely made upon the skin before the muscles contract and an attempt at protection is made. In a case of visceral lesion or of beginning peritonitis the rigid contraction of the muscles in closest nerve relation to the area involved will constitute a valuable diagnostic symptom. In general peritonitis the board-like, tender abdomen, the fixed diaphragm, and the thoracic breathing (to lessen movement of the abdominal viscera) are all phenomena to be understood only by recalling the correlation of the nerves involved. The flexion of the thighs (to remove pressure from the tender surface and to relax the muscles as much as possible) is a secondary symptom due to the same cause. The condition is in strong contrast with that seen in intestinal spasm (*colic*), in which, although the patient may be doubled up with pain, pressure gives relief and the loose, relaxed abdominal muscles may be moved easily and freely over the underlying viscera. The intestinal distention and paresis of peritonitis are due partly to the involvement of the nerve-plexuses of the gut and partly to the extension of inflammation to its muscular walls. They are increased by later vasomotor paralysis and by fermentative decomposition of intestinal contents.

Other phenomena common to many abdominal lesions, but especially to those affecting the peritoneum, are due to the relation of the nerves of the latter to the great abdominal nerve-plexuses. They have been grouped by Gübler under the term *peritonism*, are independent of toxæmia, and are essentially the symptoms of "shock,"—subnormal temperature, a running pulse, pallor or lividity, quick, shallow breathing, and great mental and physical depression. The more distinctive peritoneal symptoms are vomiting (although that is not uncommon in many forms of shock) and generalized abdominal pain becoming epigastric or umbilical, and later—if peritonitis develops—associated with tenderness. In illustration of this relation of nerves and nerve-centres, Treves says, very truly, that almost all acute troubles within the abdomen begin with the same group of symptoms, and that until some hours have elapsed it is often impossible to say whether a violent abdominal crisis is due to the perforation of an appendix or other portion of the intestine, the bursting of a pyosalpinx, the strangulation of a loop of gut, the passage of a gall-stone, the rupture of a hydatid cyst, an acute infection of the pancreas, the twisting of the pedicle of an ovarian tumor, or a sudden intraperitoneal hemorrhage.

The later symptoms of peritonitis—the board-like rigidity of the abdominal muscles, the tenderness, the meteorism, the intestinal paresis or paralysis, and the ascitic dulness in the flanks—require no further anatomical explanation. The factors already described, plus the existence of profound toxæmia, sufficiently account for them.

Chronic peritonitis of the proliferative type (said to be found frequently in the subjects of chronic alcoholism) is attended by great thickening followed by fibroid contraction, which, in accordance with the locality chiefly involved, may cause (*a*) constriction of the gastro-hepatic omentum with pressure on the portal vein and resulting serous effusion ; (*b*) diminution in the volume of the liver from perihepatitis ; (*c*) thickening of the omentum, which forms a hardened roll lying transversely between the colon and the stomach ; (*d*) shortening of the mesentery so that the intestines are drawn into a rounded mass, situated in the mid-line and feeling like a solid tumor ; (*e*) thickening and contraction of the intestinal walls, the mucous membrane being thrown into folds like the valvulæ conniventes ; (*f*) the formation of cicatricial bands attached at their ends to intestine and parietes or to two portions of the gut, and under which other coils of intestine may pass and become strangulated.

Tuberculous peritonitis is the most common chronic form of the disease. The infection—especially in children and males—usually proceeds from the digestive tract through the retroperitoneal lymphatics ; or from the lung or pleura and bronchial lymph-nodes by the same route ; or, less frequently, directly from ulcers within the intestine ; in women it often enters through the Fallopian tubes. It may be conveyed by the blood.

Of the conditions described as due to chronic peritonitis, the omental thickening and the retraction and thickening of intestinal coils are frequently present. Agglutination of these coils is apt to occur and to contribute to the sense of resistance which may be erroneously interpreted as indicating the presence of a tumor. In addition there are apt to be (*a*) a sacculated exudation in which the effusion is limited and

confined by adhesions between the coils of gut, the parietal peritoneum, the mesentery, and the abdominal or pelvic organs (Osler); and (*b*) enlargement of the mesenteric glands.

The existence of a superficial periumbilical area of redness and thickening is said to be a symptom of this variety of peritonitis (Fagge), and is even thought to be pathognomonic (Henry). It may follow adhesion of intestine to the inner parietes, or, more probably, is due to extension of the inflammation of the parietal peritoneum along the track of the obliterated umbilical vessels.

Localized peritonitis should be briefly considered from the topographical standpoint.

Pelvic peritonitis, usually due to infection by way of the uterus and Fallopian tubes, is of relatively lessened danger on account of (*a*) the fact that the source of bacterial supply is not large, the endometrium possessing a high degree of vital resistance and its secretion rendering its cavity in most instances sterile (Wardlassel); (*b*) the comparatively low virulence of the bacteria most frequently found in tubal infection, the gonococcus and bacillus tuberculosis; and (*c*) the opportunity usually afforded (by the thickness and immobility of the subperitoneal tissues involved) for the formation of competent adhesive barriers, including those which seal the opening of the tube and confine the infection to the latter and its vicinity (Fowler).

Puerperal peritonitis is much more serious, owing to the anatomical conditions associated with pregnancy—chiefly the vastly greater size and vascularity of the uterus and the enlargement of its lymph-channels—and to the minor traumatisms to the endometrium which occur even in physiological parturition. These offer an opportunity for increased dosage of bacteria and of their toxins. The danger is increased by the fact that the invading organism is apt to be a streptococcus and by the usual post-partum diminution of vital resistance.

Subdiaphragmatic peritonitis may be confined to the space between the arch of the diaphragm and the upper surface of the liver to the right or left of the suspensory ligament. It is apt to assume a suppurative form. It may follow (or precede) a pleural or pulmonary infection. It is commonly mistaken for an empyema. The infection is, of course, at its onset within the greater cavity of the peritoneum, but is often soon shut off by adhesions. When it has followed a perforation of the stomach or duodenum, the abscess usually contains air (pyo-pneumothorax subphrenicus), the diaphragm may be pushed up to the level of the second or third rib, the liver is depressed, there is bulging of the right thorax, and the physical signs are those of pneumothorax (Osler).

The variety of subdiaphragmatic peritonitis which involves the *lesser peritoneal cavity* may originate in gastric, duodenal, or colic perforations, in pancreatic disease, or in other ways. The communication with the greater peritoneum is soon cut off by adhesive inflammation of the edges of the gastro-hepatic omentum at the foramen of Winslow.

Distention of the lesser sac with serum or with pus follows and first causes an epigastric swelling, extending by gravity to the umbilical region; on account of the lesser resistance offered by its left boundary—the lieno-renal ligament—as compared with that of the gastro-hepatic omentum, and because the lesser sac extends farther towards that side, the swelling may appear later in the left hypochondriac region. As the floor of the space is formed by the upper layer of the transverse mesocolon, the colon is depressed and never lies in front of or above the enlargement, as it does in cases of renal tumor. As the space lies below and behind the stomach, distention of the latter, if with liquid, will render the swelling less palpable, but may apparently increase its area of dulness; if with air, will convert the dulness into resonance and prevent recognition of the swelling by touch.

Spontaneous evacuation of a subdiaphragmatic abscess may take place into any of the surrounding viscera or into the general peritoneal cavity, but the pus usually enters the pleural cavity or the thorax either by direct ulceration and perforation of the diaphragm or, more circuitously, through the weakened intervals between the sternal, costal, and vertebral portions of that muscle.

The *appendicular* and *subhepatic* varieties of localized peritonitis have been sufficiently described in connection with the organs involved.

Cancer of the peritoneum is occasionally primary, but is usually due to extension from the stomach, uterus, ovaries, liver, or other organs. The irregular mass of a carcinomatous omentum cannot be distinguished by touch from the similar tumor due to chronic peritonitis.

The *peritoneal cavity* as a whole—the interval between adjacent visceral surfaces or between such surfaces and the parietes—may be scarcely more than a potential space, containing enough serous fluid for purposes of lubrication, or may be more or less distended by an effusion of the same fluid,—*ascites.* Such effusion may result from (*a*) infection followed by chronic inflammation; (*b*) abdominal tumors, causing irritation and pressure; (*c*) obstruction of the portal circulation, either terminal, as in hepatic cirrhosis, or by pressure on the vein itself in the gastro-hepatic omentum, as from certain pancreatic or duodenal growths, aneurism, or the exudate of a chronic peritonitis (*vide supra*); or (*d*) from conditions producing a general dropsy (of which the ascites is but a part), such as cardiac or renal disease, chronic empyema, or pulmonary sclerosis. Ascites is recognized by (*a*) a flat abdomen bulging at the flanks, with prominent umbilicus; (*b*) dulness in the flanks varying with change of posture; (*c*) resonance over the uppermost part of the abdomen in either dorsal or lateral decubitus (from floating upward of the intestine); (*d*) fluctuation. Sudden withdrawal of ascitic fluid may cause syncope in persons with pre-existing cardiac lesions by diminishing intra-abdominal pressure, permitting a dilatation of the deep circumflex iliac, the deep epigastric, the lumbar and other deep abdominal veins, and thus suddenly lessening cardiac blood-pressure.

The difference between the peritoneal cavity and the abdominal cavity should not be overlooked by the student. A number of the abdominal viscera are not intraperitoneal, but lie more or less completely behind that membrane. Thus the kidney and pancreas and certain aspects of the ascending and descending colon and duodenum may be wounded, or may be the subject of infectious disease, without involvement of the peritoneum, while similar wounds or infections of the liver, spleen, stomach, or small intestine would necessarily include it to some extent.

The *parietal peritoneum*, the least sensitive portion of the membrane (*vide supra*), is thickest below and posteriorly, and is there connected loosely with the abdominal wall by relatively abundant subperitoneal cellular tissue containing fat. This loose connection permits it to be stripped forward, as in some operations on the kidneys or ureters or on the iliac vessels. About the umbilicus and along the mid-line of the abdomen it adheres much more closely. It is strong, bearing a weight of fifty pounds (Huschke); distensible, as shown by the gradual stretching it undergoes in ascites, during pregnancy, or in a hernial sac; and elastic, as in such cases it returns to its normal dimensions when the distending cause is removed. It may be ruptured by sudden force without injury being done to the underlying viscera.

From its superficial position, the *greater omentum* is often involved in penetrating wounds of the abdominal wall. Wounds of the omentum are not in themselves serious, except from hemorrhage. The rapid adhesive inflammation which follows injury to the omentum, as to other parts of the peritoneum, may act beneficially by leading to the closure of an intestinal wound or perforation before extravasation occurs, or by favoring the localization of an area of infection. It is sometimes utilized by the surgeon to reinforce an intestinal suture or to cover intestinal defects, especially in the cæcum (E. Senn); or to protect the general peritoneal cavity, as in some operations on the bile-ducts. Through inflammatory adhesions, portions of the omentum may act as bands beneath which a loop of gut may be strangulated, or such a loop may pass through an aperture in the omentum itself and become strangulated. The omentum is constantly found in sacs of ordinary herniæ or may constitute their only contents (epiplocele), especially in umbilical and frequently in femoral herniæ. It almost always contracts adhesions to the neck or other portion of a hernial sac, if the hernia is not kept permanently reduced. It then prevents reduction. It is found oftener in left-sided herniæ, because it was developed from the mesogastrium and inclines somewhat towards that side. It is very vascular, and has—through accidental adhesions—maintained the blood-supply of an ovarian tumor the pedicle of which has been twisted so as to occlude its vessels. Its vascularity and rapid adhe-

sion to other peritoneal surfaces have been utilized in an operation for the relief of the portal congestion in certain forms of hepatic cirrhosis (page 1727).

The Mesentery.—The length of this portion of the peritoneum is of importance in its relation to the causation and the forms of hernia, in connection with which it will be referred to. From its oblique attachment it results, that in an intraperitoneal right-sided hemorrhage the blood is first conducted into the right iliac fossa; if the hemorrhage takes place to the left of the mesentery, the blood descends directly into the pelvis (Treves). Collections of blood are said to be more common in the right than in the left iliac fossa. Treves has shown that, in addition to certain slit-like holes due to injury, there are others which are congenital defects in the mesentery, and has called attention to the fact that the latter are round; are in the lower ileum; are surrounded by an anastomotic arch between the ileo-colic branch of the superior mesenteric artery and the last of the intestinal arteries; that the area is often the seat of atrophied peritoneum; and that fat, visible blood-vessels, and glands are absent. Herniæ of knuckles of gut through this cribriform area of mesentery could occur with comparative ease.

The use of the mesentery as a means of recognition of a particular portion of gut during operative procedures has been described (page 1657).

The practical relations of the *peritoneal fossæ* and folds will be considered in the section on hernia (page 1765).

PRACTICAL CONSIDERATIONS: ABDOMINAL HERNIA.

Abdominal hernia would be correctly defined, in the great majority of cases, as the protrusion of any abdominal viscus from the cavity of the abdomen, and if the term were limited to include protrusion of only portions of the small intestine (jejunum and ileum) and of the omentum, it would still embrace by far the larger number of herniæ. Intra-abdominal herniæ occur, however, in which a portion of the intestine passes from the general into the lesser peritoneal cavity or into one of the various peritoneal fossæ or recesses. The resulting evil effects in both cases are due not to the protrusion but to the secondary changes that follow the displacement of the gut (incarceration, strangulation). It is well, therefore, to subdivide abdominal herniæ into *external* and *internal*, and in the latter variety to recognize the necessary modification of the above definition.

External Hernia.—The general conditions that predispose to or actually produce external hernia are those associated with (1) increased intra-abdominal pressure and (2) decreased resistance of the abdominal wall.

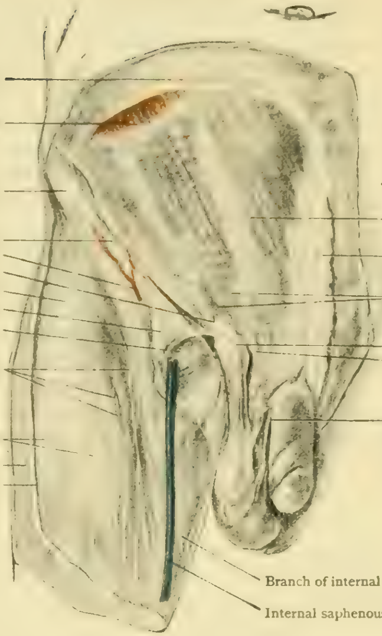
1. Under the former should be placed (*a*) occupations that necessitate much muscular effort, particularly if it is in the direction of lifting heavy weights, or is exerted while the person is in a stooping posture (*vide infra*), or if, at the same time, increased respiratory effort is required, so that during forced inspiration the diaphragm aids in augmenting the outward pressure of the abdominal viscera; (*b*) diseases causing vesical or rectal tenesmus; (*c*) respiratory diseases producing chronic or violent coughing, or inspiratory obstruction.

2. Decreased resistance of the whole abdominal wall may be due to (*a*) debilitating illness, (*b*) old age, (*c*) prolonged distention (ascites, abdominal tumor, repeated pregnancies, (*d*) excessive corpulence, or (*e*) emaciation. The last two causes are assumed to act as follows: with the occurrence of general emaciation, the fatty tissue filling up the hernial orifices usually disappears, and these places, which are already less resistant, become more yielding and relaxed; with the rapid appearance of obesity there is an increase in the amount of the subperitoneal areolar tissue, and this consequently results in a greater mobility of the peritoneum. The traction of a rapidly growing subperitoneal lipoma upon the peritoneum, to which it is tightly adherent, is also a factor in the development of a hernial sac, although it does not follow that this method of origin is frequent or, as Roser asserted, the usual one (Sultan).

The disappearance of fat and connective tissue in emaciation has been thought (Macready) particularly to favor the occurrence of femoral hernia.

Other predisposing causes are as follows: *Age.*—Hernia is very common during the first year of life. Its frequency then is probably due to (*a*) the existence of

FIG. 1479.

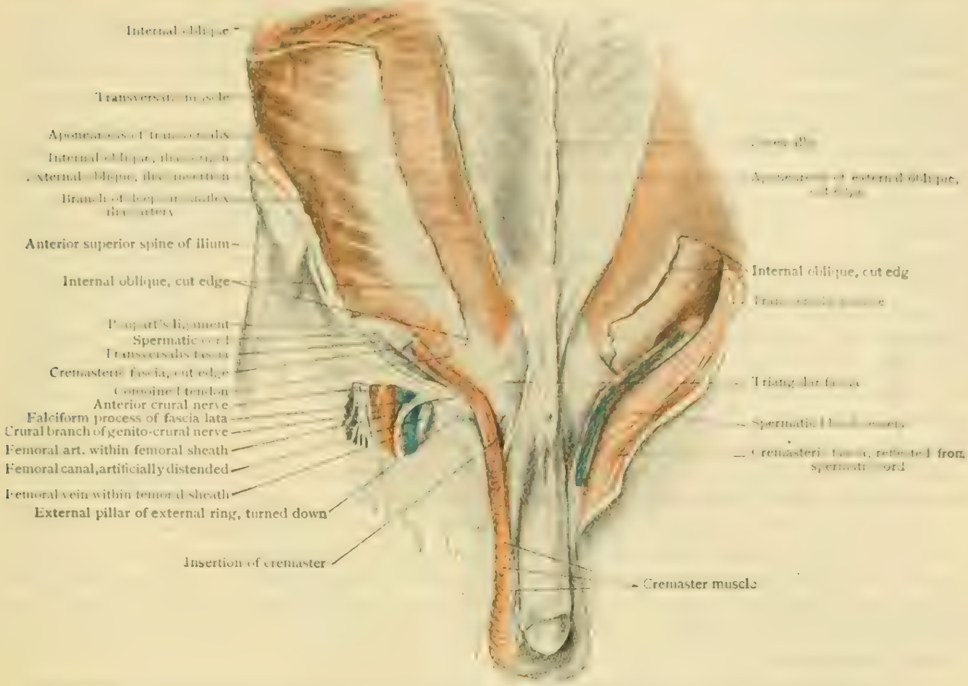


Superficial dissection of inguinal region; spermatic cord is seen issuing from external abdominal ring; intercolumnar fascia has been artificially distended by injection of fluid; saphenous opening is closed by cribriform fascia.

FIG. 1480.

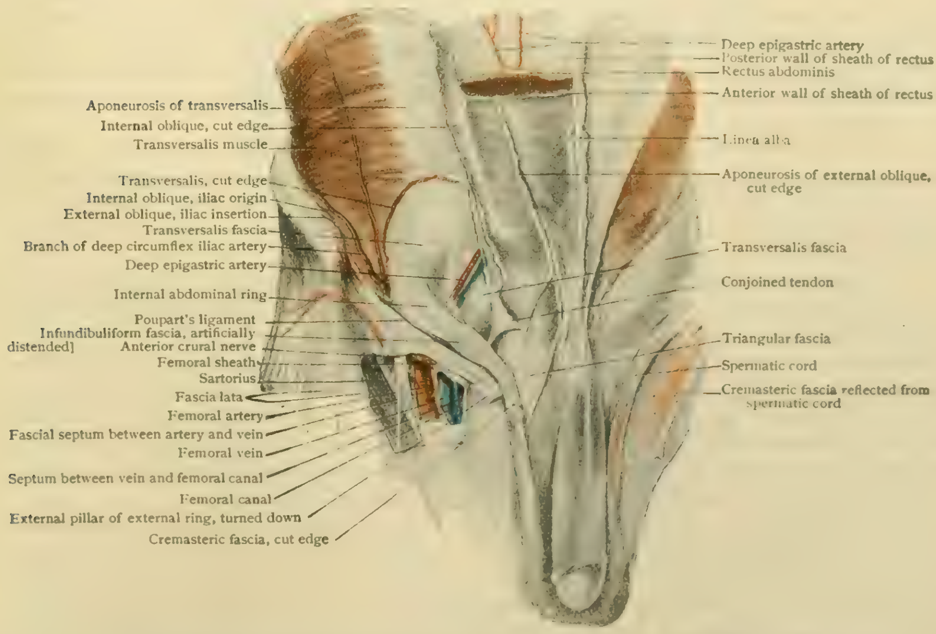
Deeper dissection in which external oblique has been partially removed, exposing spermatic cord lying in inguinal canal; cribriform fascia removed to show saphenous opening.

FIG. 1481.



Internal oblique muscle has been partially removed, showing fibres of transversalis arching over spermatic cord to reach conjoined tendon; fascia lata has been opened to expose femoral vessels lying within sheath; femoral canal has been artificially distended.

FIG. 1482.



Transversalis muscle has been partially cut away to expose transversalis fascia; spermatic cord is seen issuing from internal abdominal ring, covered by infundibuliform fascia, which has been artificially distended; anterior layer of femoral sheath has been removed showing femoral vessels and canal; anterior wall of sheath of rectus has been opened above upper part of muscle removed and posterior wall of sheath exposed.

developmental defects ; (*b*) the presence in the abdomen of portions of the pelvic organs increasing intra-abdominal pressure ; (*c*) the habitual flexion of the thighs on the abdomen in infants, relaxing the tissues about the hernial orifices ; (*d*) the extreme shortness of the inguinal canal, the internal ring then lying almost directly behind the external ring, so that the canal is about equal in length merely to the thickness of the abdominal wall. The diminution in frequency during childhood is due to the improvement in posture, to the lessening in size of the abdominal rings and to the shortening of the tissues about them, and to the lengthening of the interval between the rings as the ilia grow and incline outward and the internal ring follows them,—*i.e.*, to the formation of the inguinal canal with its valve-like resistance to the protrusion of viscera. The increase in frequency as puberty approaches and is passed is due to the more active habits of life and the assumption of occupations often laborious. It may also be due to a slight extent to the fact that until the pelvis has fully developed the femoral ring and canal scarcely exist, and that therefore the femoral variety of hernia is rarely found before that time of life. Later in life hernia is still more frequent, although it, like aneurism, lessens in numbers as old age draws on. This is due to the fact that although in both instances the predisposing cause—the weakness of vessels or of the abdominal wall—may be said usually to increase when the active period of life is passed, the exciting causes due to occupation and muscular effort diminish with relatively greater rapidity.

Sex.—Hernia is more frequent in males because (*a*) the structures connected with the male genitalia are more often the subject of developmental defects (*vide infra*), and (*b*) the inguinal canal in the female is narrower (containing only the round ligament) and longer (the distance between the anterior superior iliac and the pubic spines being greater), and for both these reasons offers less opportunity for the descent of viscera.

The descent of the testicle and the associated changes, which are often imperfect, sufficiently account for the great frequency of inguinal (92–95 per cent.) as compared with all other forms of hernia in males.

In females femoral hernia is less common than inguinal hernia. It, is however, relatively more common than in males because (*a*) in females Gimbernat's ligament (*q.v.*) is narrower, thus increasing the area of the femoral ring ; and (*b*) it is weaker and less firmly attached, and accordingly offers less resistance to visceral protrusion. In 100 ruptured persons the percentages as to inguinal and femoral hernia in the two sexes are as follows : male inguinal, 83.5 ; female inguinal, 8.5 ; female femoral, 5.9 ; male femoral, 2.1 (Macready).

The extent of the influence of a certain *shape* of the abdomen—with lateral bulgings parallel with and just above Poupart's ligament and extending above the level of the crest of the ilium—is doubtful, but it certainly indicates a laxity of the abdominal wall, and just as certainly is often, as a precedent condition, associated with hernia.

The almost invariable preponderance of right-sided hernia in all varieties, at all ages, and in both sexes has been variously attributed to (*a*) the greater bulk and weight of the liver ; (*b*) to right-sidedness in walking and lying, and to the greater strain on the muscles of the right side caused by "right-handedness ;" (*c*) to the inclination from left to right of the mesentery of the small intestine as it descends ; (*d*) to the greater frequency of incomplete descent of the testis and of a patulous funicular process on the right side ; and (*e*) to the larger capacity and circumference of the right side of the pelvis (Knox, Macready) as compared with the left, causing a corresponding increase in the size of the right femoral ring.

External herniæ are influenced as to the *site* of their protrusion by anatomical conditions causing a diminution over certain localized areas in the resistance of the abdominal wall to intra-abdominal pressure. These conditions depend usually upon the necessity for the passage from within out of (*a*) normal structures such as the spermatic cord (*oblique* or *external inguinal hernia*) or the round ligament (the *labial* variety of *oblique hernia*) ; or (*b*) such as the larger vessels or nerves (*umbilical, femoral, obturator, sciatic herniæ*) ; or (*c*) upon the weakness or absence at given points of some of the components of the abdominal wall, as at the internal inguinal fossa or the supravesical fossa (*direct* or *internal inguinal hernia*), along the linea

alba or the linea semilunaris (*ventral hernia*), through the pelvic diaphragm,—the coccygeus and levator ani (*perineal hernia*); or through Petit's triangle (page 539) or the superior lumbar triangle of Grynfelt and Lesshaft (page 1777), or "Braun's space" (page 1777) (*lumbar hernia*). Other varieties depend upon (*d*) congenital defects, as in some forms of *inguinal*, *umbilical*, *ventral*, and *diaphragmatic hernia*; or in the varieties of *properitoneal* or *interstitial hernia* that accompany misplaced or undeveloped testes; or (*e*) pathological changes, as in those *ventral herniæ* that follow abscesses or wounds.

FIG. 1483.

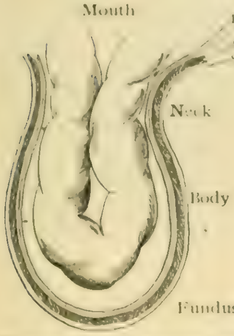


Diagram showing general components of external abdominal hernia.

This classification, although not exhaustive, will serve as a basis for the later and more detailed consideration of the anatomical factors concerned in the production of special external herniæ and of their symptoms.

The component parts of an external abdominal hernia (Fig. 1483) are (1) the *sac*, consisting of distended and protruding parietal peritoneum, and subdivided into (*a*) the *mouth*, the aperture corresponding to the internal hernial orifice; (*b*) the *body*, the expanded protruding portion, the lowest portion of which is called the *fundus*; and (*c*) the *neck*, the constricted portion connecting the body and mouth; and (2) the *contents*, which in the order of frequency are ileum, omentum, jejunum, sigmoid, cæcum, and transverse colon. More rarely the ascending and descending colon, the bladder, the ovary, and the various abdominal viscera, with the exception of the liver, have been found among the contents of herniæ.

Inguinal hernia, by far the most frequent of all the varieties of hernia, (95–97 per cent. in males, 55–60 per cent. in females), may best be studied anatomically by considering its mode of production when, (*a*) as a direct result of some developmental defect, it is present at or soon after birth; (*b*) the hernial sac being present congenitally, the hernia follows some increase of intra-abdominal pressure; or, (*c*) as a consequence of a less marked—or less complete—original defect or of

FIG. 1484.

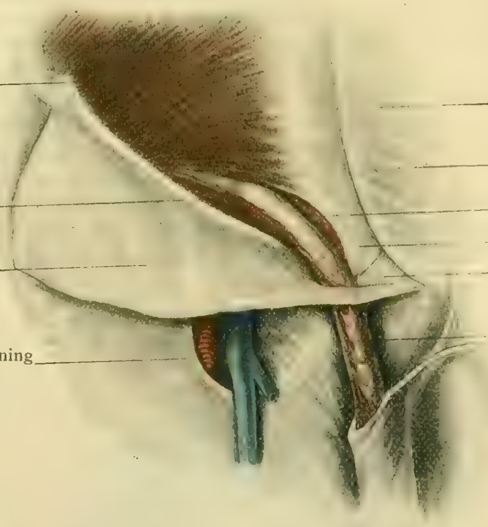
Dissection of right inguinal region, showing external abdominal ring and saphenous opening in fascia lata.

an acquired defect (*vide supra*), the hernia develops in the presence of causative factors (page 1759).

Acquaintance with the changes in the abdominal wall and peritoneum involved in the descent of the testis is necessary to an understanding of the anatomy of inguinal hernia. Although these changes are described with the development of the testicle (page 2040), the chief features of the process may be noted here with advantage.

By the end of the second fœtal month the developing testicle lies behind the peritoneum at the side of the upper lumbar vertebræ, the epididymis and later the testicle being attached to a fibro-muscular band, the *genito-inguinal ligament*, which stretches from the sexual gland to the lower part of the anterior abdominal wall. During the third month, guided by this attachment, the testicle migrates from its primary location to a position which later corresponds to the internal abdominal ring About this time the muscular, fascial, and peritoneal layers of the abdominal wall show a protrusion in the inguinal region which results in the production of a sac, the *inguinal bursa;* this deepens and extends into the scrotal fold, which meanwhile is formed independently as an integumentary fold. The genito-inguinal ligament,

FIG. 1485.



Dissection of right inguinal canal; aponeurosis of external oblique has been cut and turned outward.

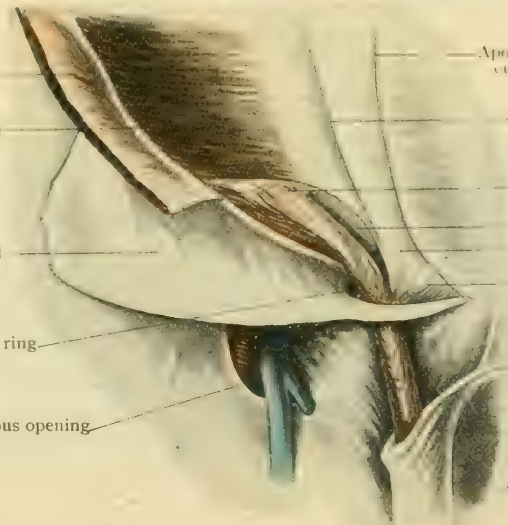
being attached to the structures undergoing evagination, extends into the inguinal bursa. The muscular tissue within the wall of the latter is derived from the internal oblique and transversalis and constitutes the cremaster. The lining of the inguinal bursa is obviously the direct continuation of the general serous membrane of the abdominal cavity and later constitutes the *processus vaginalis peritonei*. Thickening of the lower end of the genito-inguinal ligament produces an elevation of the floor of the bursa known as the *inguinal conus*, a structure, however, that in man is very feebly developed as compared with that found in some lower animals. Subsequently, during the seventh and eighth months, the inguinal conus and the attached testicle are drawn downward into and through the inguinal canal until, shortly before birth, the sexual gland gains its permanent position in the scrotum. The rudimentary conus and the genito-inguinal ligament, which together correspond to the structure usually described as the *gubernaculum testis*, become progressively shorter and smaller as the testicle descends, their remains constituting the *scrotal ligament*, the subserous band which permanently attaches the tunica vaginalis and the testicle to the surrounding tissue of the walls of the scrotum.

The original retroperitoneal position of the testicle is always retained, this organ and the accompanying constituents of the spermatic cord descending outside the

peritoneal pouch which extends into the scrotum. For a time free communication with the abdominal cavity is maintained by the now tubular processus vaginalis; usually, however, by the time of birth, or shortly after, this canal is obliterated, the isolated lower end of the peritoneal pouch persisting as the sac of the *tunica vaginalis* which almost surrounds the testicle. The peritoneal evagination occurs in both sexes, in the female extending into the labium majus as the diverticulum of Nuck; this usually early disappears, but, as a great rarity, may remain as an open peritoneal process at the time of puberty (Merkel).

If obliteration of the processus vaginalis does not occur, a congenital hernial sac results (Fig. 1488), and this may become a hernia, either at birth or in later life, by the descent of some of the abdominal viscera. During their descent the testicle and spermatic cord obtain more or less extensive investments of such parts of the abdominal walls as have taken part in the formation of the original bursa inguinalis. From within outward these would be, therefore, (1) *peritoneum*, after obliteration of the stalk of the peritoneal pouch, however, coextensive with only the tunica vaginalis; (2) *infundibuliform fascia* (tunica vaginalis communis), continued from the transversalis fascia; (3) *cremaster fibres*, from the transversalis and internal oblique muscles, blended by areolar tissue into the cremasteric fascia; (4) *intercolumnar fascia*, from the aponeurosis of the external oblique. In addition to these coverings from the abdominal wall, the envelopes forming the scrotum proper contribute (5) the modified *superficial fascia* or *tunica dartos* and (6) the *skin*. Unusual attachments of the gubernaculum below to the tuber ischii and sphincter ani account for some of the forms of testicular ectopia (*q.v.*). Attachments above to the peritoneum of the cæcum or ileum, or of the sigmoid, or to the loosely attached peritoneum lining the iliac fossa, account in part for the formation of the sac in *infantile* hernia (*vide infra*).

FIG. 1486.



Dissection of right inguinal canal; external and internal oblique cut and reflected, exposing transversalis muscle.

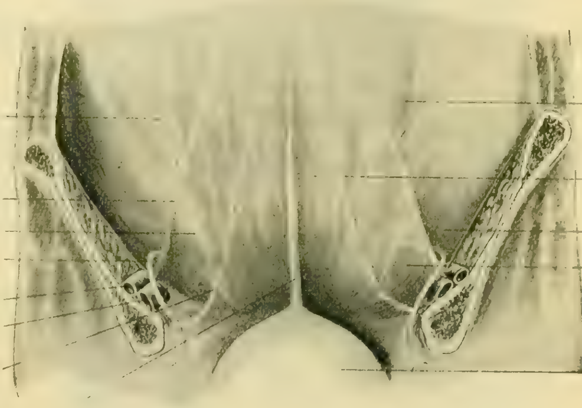
The strength of the attachments of the gubernacula to the testes and to the dartos is shown by the fact that in cases of elephantiasis scroti, although the enormously thickened skin and dartos may form a tumor reaching to the knee, the testicles will usually be found near its lower extremity.

The next step in the anatomical study of inguinal hernia should consist in a survey of the inner surface of the abdominal cavity in the inguinal, iliac, and hypogastric regions (Fig. 1487). This will show that the space between the lateral wall of the abdomen and the mid-line—marked by the peritoneal fold over the urachus

(*plica urachi*)—is divided on each side into two shallow depressions by a slight elevation of the peritoneum over the deep epigastric artery (*plica epigastrica*) running from a little internal to the middle of Poupart's ligament to a point on the outer edge of the rectus muscle about one-third the distance between the level of the symphysis pubis and that of the umbilicus. The outer of these depressions is called the *external inguinal fossa* (hernial fossa). The inner contains a triangular space known as Hesselbach's triangle, bounded by the *plica epigastrica*, the outer edge of the rectus, and Poupart's ligament. The whole inner region—extended to the mid-line—is further subdivided by a line corresponding to the peritoneal fold over the obliterated hypogastric artery (*plica hypogastrica*) into two other fossæ, the *internal inguinal* and the *supravesical*, which are of use as aids to the description of hernia, but, viewed as mechanical factors, have little bearing on its production.

The external inguinal fossa is deepened just to the outer side of the epigastric artery into a slight pouch (Fig. 1487), which marks the point of exit of the spermatic cord from the abdomen, and therefore the site of the internal abdominal ring and of the mouth of one form of inguinal hernia,—the external, oblique, or indirect. On the external surface of the abdomen this pouch corresponds to an area about three-quarters of an inch in circumference, situated a finger's-breadth above the middle of Poupart's ligament. To the inner side of the epigastric artery are two other and

FIG. 1487.



Posterior surface of anterior abdominal wall of formalin subject.

still slighter depressions corresponding approximately in position to the outer part of the posterior wall of the canal and to the external abdominal ring (page 1771) and the lower fifth of the inguinal canal. When viscera make their way outward from either of these depressions as the point of departure, the resulting hernia is known as *direct* because it does not pass through the entire length of the inguinal canal, but takes a shorter route, or *internal* because it lies to the inner side of the epigastric artery. A further examination of the structures (already described on pages 523, 524) which are related to the production of inguinal hernia will serve to explain its occurrence in certain localities and in certain forms that may now be considered separately in their simpler varieties, the rarer and more complicated being merely mentioned or altogether omitted as unessential to the anatomical study of hernia.

Oblique, *external*, or *indirect inguinal hernia*, which makes its exit from the abdomen at the internal ring, is *incomplete* if it remains in the inguinal canal, *complete* if it emerges at the external ring, and *scrotal* if it descends into the scrotum. In frequency it bears about the same relation to the other form of inguinal hernia—the direct—as inguinal herniæ do to all other forms of hernia in males,—viz., from 95–97 per cent. This frequency depends upon the following anatomical conditions. (*a*) The descent of the testicle from behind the peritoneum (page 2040), carrying with it a process (vaginal) of peritoneum, a portion of the transversalis fascia (infundibuliform fascia),

and of the transversalis and internal oblique muscles (cremaster muscle), makes its region of exit from the abdomen—*i.e.*, of its entrance into the inguinal canal—the area in the abdominal wall best adapted by reason of its weakness and its shape to favor the exit of viscera. (*b*) This spot is situated near the lowest level of the inferior zone of that cavity,—*i.e.*, at a level at which, when the size of the cavity is either temporarily decreased (as during coughing or straining), or relatively decreased (as when the upper zone is compressed by tight lacing), or actually decreased (as by intra-abdominal fat, or by a tumor or ascites), the outward thrust of the abdominal viscera is added to by their superincumbent weight. (*c*) The peritoneum over the lower part of the anterior abdominal wall is thin and loosely attached, so that it is unable to offer much effective resistance to distention by pressure from within. Such distention is favored by the funnel-shaped depression at this point, and, having once begun, its influence in localizing a hernia is obvious. (*d*) The union of the iliac fascia with the transversalis fascia, which is strongest in the immediate vicinity of Poupart's ligament, presents an insuperable obstacle to the descent of hernia external to the internal ring. (*e*) The conjoined tendon of the transversalis and internal oblique muscles inserted into the crest of the pubes and the iliopectineal line is strong internally, but has an ill-defined outer edge; while that portion of the tendon which is derived from the internal oblique has generally a less extensive attachment than that from the transversalis muscle, so that the space between the border of the rectus and the internal ring is closed by the two tendons conjoined at the innermost part, farther outward by the transversalis tendon alone, while near the entry of the cord there may be a space unprotected by tendon or muscle (Macready). The thinnest and least protected portion of the inner—posterior—wall of the canal is therefore that adjacent to the inner edge of the internal abdominal ring (Ibid.). It should be noted that Treves is inclined to consider the resistant power of the normal abdominal wall as less over Hesselbach's triangle than over the external inguinal fossa; but even if this is true, the existence of the internal ring and of the canal more than compensates for it in favoring hernia.

These facts sufficiently explain the frequency of oblique inguinal hernia of the *acquired* form (*vide infra*),—*i.e.*, the form in which the congenital deficiencies or definite pathological changes next to be mentioned are not demonstrable, although it is not unlikely that some original or acquired defect of the abdominal wall in the neighborhood of the hernial orifices is present in the great majority of cases of hernia of this as of all varieties. (*f*) The not infrequent total or partial patency of the vaginal process gives rise to a number of subvarieties of inguinal hernia (*congenital*, *infantile*, *funicular*), all of which are oblique,—*i.e.*, enter the inguinal canal at the internal ring and to the outer side of the epigastric artery. These herniæ, depending on anomalies in the closure of the processus vaginalis, have been variously subdivided and defined, often with unnecessary complexity. It will suffice here to say that *congenital* hernia (Fig. 1488) is due to complete patency of the vaginal process, the cavity of which is directly continuous with the cavity of the abdomen, the sac of the hernia enclosing both its visceral contents and the testicle, which lie in contact. Although the condition leading to the formation of this hernia is truly congenital, the hernia itself is very rarely in existence at the time of birth, but is apt to occur in early life when intra-abdominal pressure is either habitually or suddenly increased. It should be remembered that, although a true congenital hernia necessarily depends upon a patent processus vaginalis, patency of the process may exist without hernia. A fold of peritoneum at the edge of the infundibuliform fascia partly screening the abdominal opening of such a process has been described and has been thought to aid in preventing hernia (Macready). In women patency of the canal of Nuck acts similarly as a predisposing cause of congenital hernia, which is, however, of great rarity, on account of the narrowness of the canal itself, the fact that its internal orifice is still smaller, and—supposedly—by reason of the relatively larger size and greater distinctness in the female than in the male of the peritoneal and fascial fold covering the entrance to the canal.

Infantile hernia (Fig. 1489) results from occlusion of the processus vaginalis at the internal ring only, the visceral pressure, aided by the attachments of the gubernaculum testis above described, carrying this septum and the neighboring perito-

neum downward to constitute a sac that descends behind the tunica vaginalis, especially if the latter is capacious, as it is apt to be when its upper limit is at the internal ring. A hernia of this variety has, therefore, between the skin and the contents three layers of serous membrane, two of the tunica vaginalis and one of peritoneum (its own sac) connected with one another at the neck. Not uncommonly, however,—as might be expected from the tendency of serous membranes to adhesive

FIG. 1488.

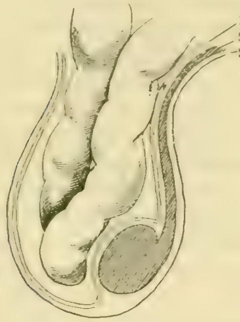


Diagram of congenital hernia, showing relation of hernial sac to peritoneum.

FIG. 1489.

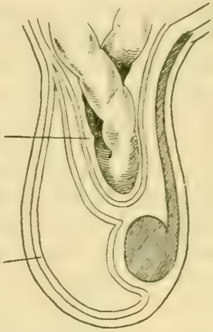


Diagram of infantile hernia, showing relation of hernial sac to tunica vaginalis.

inflammation,—the posterior layer of the tunica vaginalis is intimately blended with the front wall of the sac. Infantile hernia, while due, like the congenital variety, to anomaly in development, is even less apt to exist at birth and, in fact, is rarely seen in infancy. A variety of infantile hernia known as the *encysted* (Fig. 1490) is described, in which the intestine depresses the septum at the internal ring, making a sac which passes into instead of behind the processus vaginalis, so that the hernia has in front of it a layer of tunica vaginalis and a layer of septum (sac). This hernia is very properly described (Lockwood, Macready) as "a figment of the imagination." When, after occlusion of the process at the internal ring only, the septum gives way suddenly during some unusual intra-abdominal pressure, the intestine may descend at once into instead of behind the tunica vaginalis and lie in contact with the testicle,—a form of "congenital" hernia that appears in adult life.

FIG. 1490.

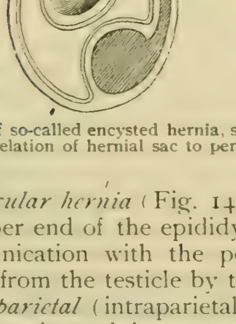


Diagram of so-called encysted hernia, showing supposed relation of hernial sac to peritoneum.

FIG. 1491.

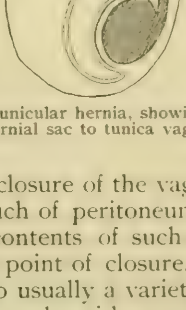


Diagram of funicular hernia, showing relation of hernial sac to tunica vaginalis.

Funicular hernia (Fig. 1491) is a sequence of the closure of the vaginal process at the upper end of the epididymis only, the short pouch of peritoneum remaining in communication with the peritoneal cavity. The contents of such a hernia are separated from the testicle by the septum formed at the point of closure.

Interparietal (intraparietal, interstitial) *hernia* is so usually a variety of oblique inguinal hernia, and is so commonly associated in the male with anomalies of the

testis, that it may be described here. It derives its name from the protrusion from the sac of an inguinal hernia (usually of the incomplete variety) of a pouch or diverticulum which insinuates itself into or between the separate layers of the abdominal wall, as (*a*) between the peritoneum and transversalis fascia (*properitoneal hernia*); (*b*) between that fascia and the transversalis muscle, or among the fibres of the internal oblique, or between the internal and external oblique muscles, or sometimes—the transversalis and internal oblique having been pushed aside, as in the descent of an ordinary *acquired* inguinal hernia (*vide infra*)—between the transversalis fascia and the external oblique muscle or aponeurosis (*interstitial hernia*); (*c*) between the external oblique aponeurosis and the skin (*superficial inguinal hernia*) (Sultan).

While the exact mechanism of the formation of these herniæ is still unknown, and the various conflicting theories—although of great anatomical interest—cannot here be set forth, it is perhaps safe to say that the following facts have a direct bearing upon the question: (*a*) a hernia, like other swellings, enlarges in the direction of least resistance; (*b*) the preponderance of the association of these interparietal herniæ with incomplete inguinal herniæ and with retained testis, in neither of which cases have the external ring and the scrotum undergone dilatation, may be due to a lesser resistance in the course of the diverticulum than at the external ring; (*c*) they are also often associated with imperfections of the abdominal wall, correlated with the anomalies of the testicle, because, as Macready says, when that organ is defective it is very probable that the parts through which it passes and with which it is so intimately associated will likewise be deficient.

The mechanism of formation of the so-called *acquired oblique inguinal hernia*—the most frequent and therefore the most important of all forms of hernia—will now readily be understood. Because of the anatomical conditions above enumerated (page 1763), and in the presence of one or more of the etiological factors, the peritoneum covering the internal ring yields to the pressure of the viscera (usually a portion of the small intestine) and, together with the latter, passes through the internal ring above the cord, the component structures of which, with the artery to the vas deferens, the cremasteric artery, the genital branch of the genito-crural nerve, and the inguinal branch of the ilio-inguinal nerve, are close to the lower margin of the ring. After entering the canal it meets with less resistance, and, aided by gravity and sometimes by prolapse of the mesentery,—a loosening or slipping down of its vertebral attachment,—which slightly increases the weight of the intestines that must be borne by the abdominal wall, descends until it reaches a point at which the resistance is greater than the forces that are carrying it downward. Its descent has been thought to be aided by the weight of masses of fat (subserous lipomata) sometimes found in the extraperitoneal connective tissue that precedes the sac and forms one of the coverings of nearly all abdominal herniæ, but this is more than doubtful. The most frequent point of arrest is at the lower part of the canal, where the rigid, non-elastic pillars of the external ring, strengthened by the intercolumnar fibres, often closely embrace the cord, and where the course of the hernia changes slightly in direction. Until it emerges from the external ring it is known as an *incomplete hernia* (bubonocele). It is obvious that, with the exception of a few congenital herniæ, every inguinal hernia must at some time have been incomplete. After emerging from the external ring it is known as a *complete hernia* and usually enters the scrotum. It then meets with but little resistance until it reaches the level of the upper end of the testicle, where it may be again arrested—often permanently—by the close connection of the coverings of the cord to the tunica vaginalis, or it may descend quite to the bottom of the scrotum (*scrotal hernia*). It lies throughout its course in front of the spermatic cord.

In females the corresponding hernia follows the round ligament through the inguinal canal and appears in the labium majus (*labial hernia*).

As the peritoneal sac and its contents follow this course from the abdominal cavity downward, they are covered by various structures that represent portions of the different layers of the abdominal wall, modified in character, however, at the time of the descent of the testis and designated by new names. The clinical importance of this list of "coverings" has been greatly exaggerated, but they have a certain

usefulness as denoting the route of the hernia, and are occasionally of value as landmarks during herniotomies or operations for the radical cure of hernia.

The sac of a complete oblique inguinal hernia (Fig. 1492) would carry with it (1) a layer of extraperitoneal connective tissue; (2) that portion of the transversalis fascia known as the *infundibuliform fascia*; (3) the muscular fibres derived from the transversalis and internal oblique muscles, and called the *cremaster muscle*; (4) the fibres from the external oblique aponeurosis that aid in strengthening the external "ring," especially the upper angle,—the *intercolumnar fascia*; (5) the *superficial fascia*,—in the scrotum the *dartos* layer; (6) the skin.

The coverings of an incomplete oblique inguinal hernia will obviously depend upon the point of its arrest, but such a hernia cannot be covered by either intercolumnar fascia or dartos.

The sac of a complete oblique inguinal hernia, if followed from within outward, would show first a puckered or pleated appearance at the mouth, due to the folds of peritoneum produced by constriction; next a portion narrow and elongated by the pressure of the walls of the canal,—the *neck*,—which in such a hernia would extend from the internal to the external ring; and finally a portion—the fundus or body—which, relieved from pressure, is usually irregularly ovoidal in shape.

FIG. 1492.

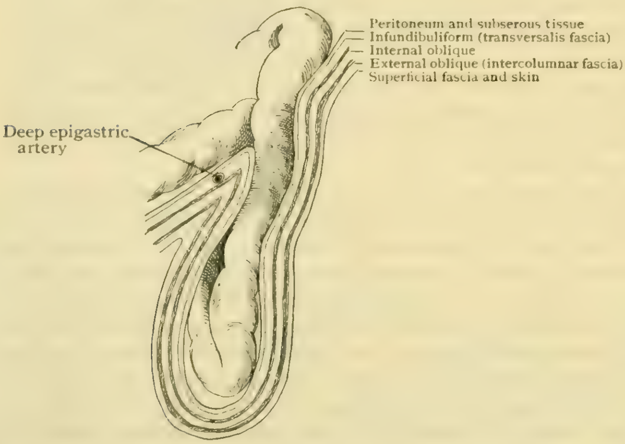


Diagram showing coverings of complete left indirect inguinal hernia.

The anatomical points at which strangulation is likely to occur are, in the order of frequency, (1) the edge of the internal ring, (2) the edge of the external ring, and (3) in the canal (from fibres of the transversalis or internal oblique), but the constriction of the contents is not infrequently due to pathological changes in the neck of the sac itself. In operating to relieve constriction at the internal ring, the relation of the epigastric artery should be remembered. The in sion should be directly upward.

Taxis.—In reducing—*i.e.*, returning to the abdominal cavity—an oblique inguinal hernia, the shoulders and thorax should be raised to relax the abdominal muscles; the thigh flexed and adducted to relax the fascia lata and external oblique aponeurosis, and thus the margins of the external ring and the anterior wall—the most unyielding—of the inguinal canal; and the pelvis elevated so as to secure by the aid of gravity a backward or upward pull on the contents of the hernia. After gentle downward traction in the line of the canal so as to remove folds and lessen lateral bulging of the sac and contents over the pillars of the external ring, and while making pressure with the thumb and fingers of one hand at that point to prevent its recurrence, the other hand encircles the fundus of the sac and with as evenly distributed force as possible makes pressure at first upward, then upward and outward,—in the line of the canal,—and finally backward.

Direct or *internal inguinal hernia* occurs in only 3–5 per cent. of cases. The reasons for its relative infrequency have been given. To understand it, the region internal to the deep epigastric artery should be examined (Fig. 1487). It has been mentioned that this region has been subdivided by a fold corresponding to the plica hypogastrica into a supravesical and an internal inguinal fossa (Fig. 1487). At the inner angle of the former we find the abdominal wall strengthened (*a*) by the presence of the rectus muscle, which extends outward as far as the pubic crest; (*b*) by Colles's ligament (*triangular ligament*, *ligamentum inguinale reflexum*), consist-

ing of the inner deeper fibres of Poupart's ligament, which turn upward and inward from the crest of the pubes in front of the insertion of the conjoined tendon and pass behind the internal pillar of the external ring to be inserted into the anterior sheath of the rectus and into the linea alba (Fig. 1486); these fibres protect the inner and posterior wall of the canal in the angle between the pubes and the rectus muscle, and as far outward as corresponds to the inner third of the external ring in males and the inner half in females (Malgaigne, quoted by Macready); (*c*) by the conjoined tendon, which becomes thinner and weaker as it leaves the mid-line.

It will be seen, therefore, that there is a space between the outer edge of the rectus and the epigastric artery in which the abdominal wall is very thin, contains no muscular layer, and is weakened anteriorly by the gap in the external oblique aponeurosis at the external ring, especially at its upper and outer angle, the posterior wall of the canal at this point not being reinforced by the presence of the conjoined tendon or Colles's ligament (Fig. 1485). This "thin spot," lying thus partly behind the external ring, is bounded internally by some aponeurotic fibres of the transversalis muscle running from the upper surface of the pubes to the rectus (*falx aponeurotica inguinalis*) and externally by similar fibres running down from the same muscle, encircling the inner border of the internal ring and fusing with the inner surface of Poupart's ligament (*ligamentum interfoveolare*) (Fig. 1493). When these two structures are broad the thin spot is narrow, and *vice versa* (Spalteholz).

FIG. 1493.

Dissection of posterior surface of anterior abdominal wall, showing relations of conjoined tendon and its expansions to internal abdominal ring.

It is perhaps intrinsically weaker than any portion of the external hernial fossa (Treves), but the infundibuliform depression at the entrance to the inguinal canal, the presence of the canal itself, and the many anomalies associated with the descent of the testis far outweigh this weakness as factors in the production of hernia.

A direct inguinal hernia may escape through (*a*) the inner inguinal fossa, between the plica epigastrica and the plica hypogastrica, which corresponds in situation to the outer part of the posterior wall of the inguinal canal,—*i.e.*, to that part formed by the transversalis fascia; it would go around the outer edge of the conjoined tendon, enter the inguinal canal a little below the internal ring, and have the same coverings as the oblique hernia, except that the general transversalis fascia would replace the infundibuliform fascia; or (*b*) the outer part of the supravesical fossa, between the plica hypogastrica and the plica urachi,—the outer and deepest part of which corresponds to the external ring,—in which case it might either also go around the outer edge of the conjoined tendon and triangular ligament, or, if those structures are thin and poorly developed, might carry them with it, so that its coverings would be (1) extraperitoneal connective tissue, (2) transversalis fascia, (3) conjoined tendon, (4) Colles's ligament, (5) intercolumnar fascia, (6) superficial fascia, (7) skin. The spermatic cord usually lies on the outer side of the sac. As many such herniæ practically issue through the lowest part of the linea semilunaris, it has been proposed to call them *ventro-inguinal herniæ*. They have no such essential

relation to the inguinal canal as have oblique herniæ, although when the peritoneal pouch first forms, and before the resistance of the aponeurosis at the external ring has been overcome, they usually enter the lower part of the canal, as the resistance in that direction is less than it is inward, towards the rectus. They are never congenital and have no definite pre-existing path. They are therefore herniæ of slow development, usually seen in adult life, especially if the local weakness of the abdominal wall is emphasized by its laxity from general muscular atrophy, or by increased intra-abdominal pressure from accumulation of fat. They are usually small, globular in shape (by reason of the shortness of the neck), do not, as a rule, descend into the scrotum, but remain above the crest of the pubes, and when reduced go directly backward into the abdomen. The orifice in the abdominal wall is easily felt, the outer edge of the rectus to its inner side, the crest of the pubes below. The epigastric artery is to the outer side of this aperture, but its pulsation can rarely, if ever, be felt Macready says: the opening in the posterior wall of the inguinal canal through which a direct hernia comes is much more accessible to examination in the living than the internal abdominal ring, so that it is quite possible, in the majority of cases, to explore the conjoined tendon with the finger and ascertain the shape and size of the opening as well as the extent to which the posterior wall has suffered. When a hernia is oblique, the posterior wall of the canal is felt as a plane surface by the finger passed into the external ring, and its attachment along the pubes can be traced. The finger is prevented from entering the abdomen till it reaches the internal ring. But in direct hernia, when fully developed, the finger at once passes into the belly over the bare pubes, and can feel the back of that bone and of the rectus muscle. No trace of the posterior wall of the canal is felt nor the margin of an opening in it. All that remains is a narrow layer of membrane which just fills the angle between the pubes and the rectus; it seems as if the triangular ligament had alone withstood the distending force of the hernia. In these cases, in which the protrusion has done its worst, all the posterior wall of the canal between the rectus and epigastric artery has gone, and the large opening has a triangular figure coinciding with the triangle of Hesselbach.

FIG. 1494.

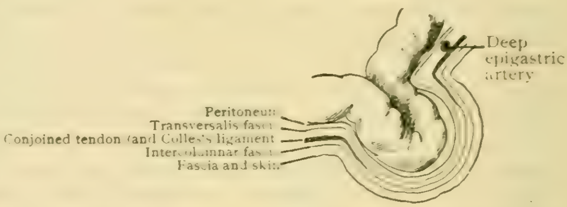
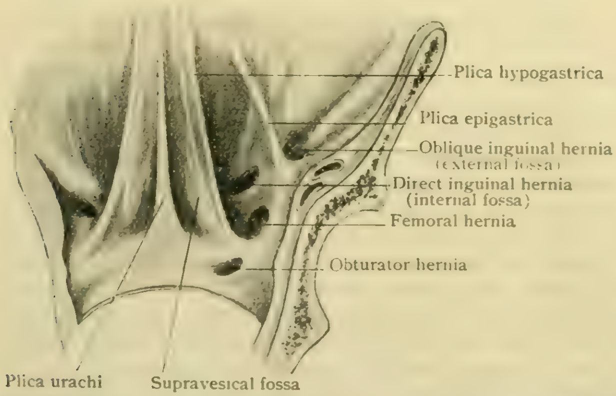


Diagram showing coverings of complete direct inguinal hernia.

FIG. 1495.



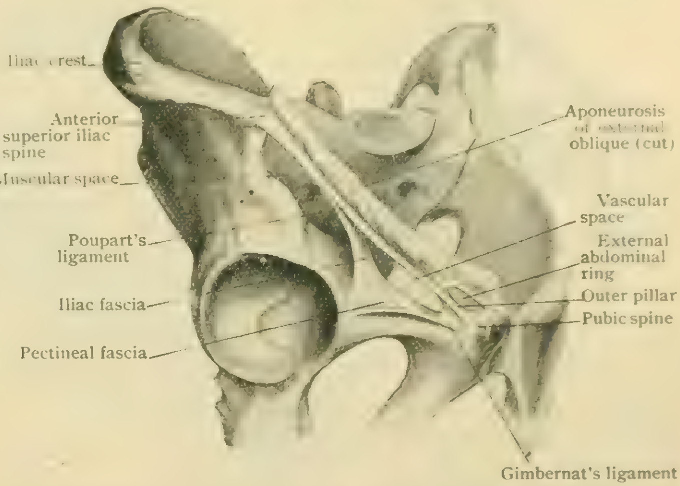
Semidiagrammatic view of posterior surface of anterior abdominal wall, showing relative positions of various forms of herniæ. (*After Merkel.*)

If strangulation occurs, it is apt to be at the external ring, and the incision for relief of the constriction should be upward with a slight inclination inward.

Large oblique herniæ (scrotal), especially when of long standing and in old persons with relaxed abdominal walls, may have the internal ring displaced so far towards the median line by the weight of the hernia that it occupies almost exactly the usual site of exit of a direct hernia. The epigastric artery will, of course, still lie to its inner side, but cannot be felt. As a rule, however, a sufficient portion of the posterior wall of the inguinal canal will be left to preserve some obliquity of the neck (Macready), by which the hernia may be recognized.

Femoral hernia is more common in females than in males for reasons already given (page 1762). It is always acquired, as the femoral "canal" is even less an actual passage than is the inguinal canal. Its upper orifice (the femoral or crural ring) (Fig. 1493) is the weakest spot in that portion of the abdominal parietes represented by the inner surface of the inguino-femoral region. The firm union of the transversalis and iliac fasciæ to the outer half of Poupart's ligament and the presence of the ilio-psoas muscle enclosed in its osseo-fascial space (*lacuna musculorum*) by the ilium and the iliac fascia offer practically insuperable obstacles to the descent of abdominal contents beneath Poupart's ligament external to the femoral vessels (Fig. 1496). Only a very few such cases have been reported. At the extreme inner angle of the ilio-pubic space, bridged over by Poupart's ligament, the pectineus muscle, covered by the pectineal fascia and Gimbernat's ligament, offers a similar resistance. Between these two muscular compartments, however, lies the space occupied by the great vessels of the lower extremity in their passage between their retroperitoneal position in the abdomen and the thigh. This space—the vascular compartment (*lacuna vasorum*)—is only partially occupied by the vessels. Their sheath is made up by the lateral union, externally and internally, of the transversalis fascia anteriorly and the iliac fascia posteriorly. This sheath does not embrace the vessels closely until it descends from one-half to three-quarters of an inch below the relatively unyielding Poupart's ligament, about opposite the upper margin of the saphenous opening,—*i.e.*, to a point at which, in the movements of flexion and extension of the thigh on the abdomen, the vessels are less liable to injurious traction or compression. It is therefore infundibuliform, and at its beginning there is a space—the *femoral ring* (*annulus femoralis*)—between the innermost side of the femoral vein, covered by a layer of fibrous tissue connecting the anterior and posterior walls of the sheath, and the outer curved margin of Gimbernat's ligament (Fig. 1496). This space varies in size with the degree of development of the latter structure, which, as has been said, is broader and stronger in males than in females, and with the size of the pectineus and ilio-psoas muscles. Its internal aspect and relations are shown in Fig. 1493. The ring is on an average from 12–15 mm. ($\frac{1}{2}$–$\frac{3}{5}$ in.) in width in men and from 18–25 mm. ($\frac{3}{4}$–1 in.) wide in women. The femoral canal leading down from it is occupied by loose, fatty areolar tissue and some lymphatic vessels. The ring itself, as seen from within, presents on its surface, covered by peritoneum, a very slight depression. Beneath the peritoneum at this point the extraperitoneal tissue is exceptionally abundant and is frequently the site of subserous lipomata which have been thought (Roser) by their traction to cause the peritoneal depression just spoken of, and even to account for the development of hernia. The septum crurale (*septum femorale*)—variously described as a condensation of the subserous tissue and as a portion of the transversalis fascia—fills in the ring and is perforated by a number of lymphatic vessels passing from the inguinal to the pelvic nodes. A small lymph-node not infrequently lies on the septum beneath the peritoneum.

FIG. 1496.



Deep dissection of right half of pelvis, showing attachments of iliac fascia.

The *boundaries* of the ring should be carefully studied in their relation to the neck of a femoral hernia. On the inner side is Gimbernat's ligament, which in child-

hood is relatively undeveloped ; its outer edge and the vein may then almost touch It is strengthened by the conjoined tendon and Colles's ligament, while some fibres of the iliac portion of the fascia lata and of the deep femoral arch (*vide infra*) also contribute to the formation of the inner boundary. On the outer side is the femoral vein. Behind lies the horizontal ramus of the pubes covered by the origin of the pectineus muscle and its fascia. In front are Poupart's ligament and the strong band of fibres running along its deep surface from the anterior superior iliac spine to the pubic spine, and known as the deep femoral arch. At the point at which the sheath of the vessels closely embraces them—the lowest limit of the femoral canal —the saphenous opening in the fascia lata (described on page 635) has somewhat the same relation to a femoral hernia that the external abdominal ring has to an inguinal hernia. After emerging from these openings neither hernia is further arrested in its progress by any strong aponeurotic barrier, and they are both therefore more likely to increase in size ; but in femoral hernia the change in direction of the axis of the fundus as compared with that of the neck is much more marked.

FIG. 1497.

Superficial dissection of left femoral hernia protruding through saphenous opening.

In its etiology femoral hernia conforms to the general laws already enumerated (page 1759). As the knuckle of gut involved presses the peritoneum before it into the femoral ring and down through the femoral canal, it carries before it (1) the *extraperitoneal tissue ;* (2) the *septum crurale*, when that constitutes a distinct layer ; (3) the *femoral sheath*, sometimes described as *transversalis fascia* because the anterior layer of the sheath is derived from that structure ; (4) the *cribriform fascia ;* (5) the *superficial fascia ;* (6) the *skin.*

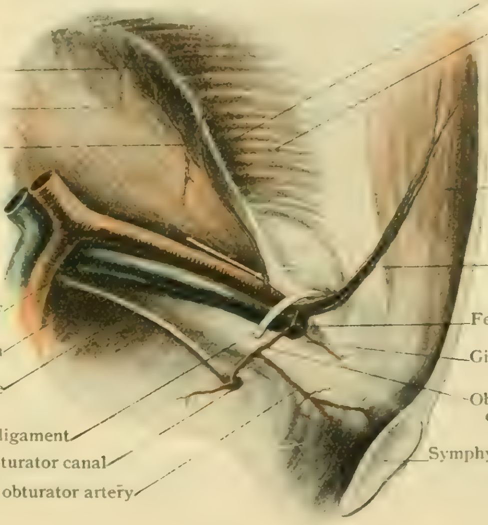
As the transverse axis of the femoral ring —parallel with that of Gimbernat's ligament —is, in the erect posture, nearly horizontal, a femoral hernia first descends almost perpendicularly. After it reaches the point of close adhesion of the sheath to the femoral vessels it takes the direction of least resistance and protrudes through the saphenous opening. Its neck is, of course, the portion of the sac between the femoral ring and the bottom of the femoral canal. The body is apt to be small and globular or hemispherical in shape.

The following anatomical relations will be found of great importance in distinguishing between femoral and inguinal hernia. (*a*) The upper edge of a femoral hernia does not, as a rule, pass above the inguinal furrow (page 670), although it may reach it,—*i.e.*, the hernia will be below a line drawn from the anterior superior spine of the ilium to the spine of the pubes. This may usually be determined by inspection. Exceptionally, on account of the stronger attachment of the cribriform fascia to the lower edge of the saphenous opening, the hernia finds its direction of least resistance after emergence from that opening to be upward, when this sign will be fallacious. (*b*) The neck of a femoral hernia is external to the pubic spine, that of a complete inguinal hernia internal to it. The already described methods for locating that process (page 349) may fail in very fat persons, especially in females. In that case the lower crease that in such persons crosses the abdomen (page 531), and which in the mid-line rests upon the symphysis pubis, will be a reliable guide to the latter point ; the bone may thence be traced outward to the pubic spine.

In the reduction of a femoral hernia—apt to be difficult on account of the narrowness of the channel of exit—the position of the patient should be that already described as appropriate when the hernia is inguinal. The thigh should be in a position of inward rotation, flexion, and adduction, to relax the fascia lata and relieve tension about the saphenous opening. After the hernia—the axis of the body of which is nearly at right angles with the axis of the neck—is drawn downward so that the axes correspond, it is gradually pushed backward and then upward.

It should be noted that in this form of hernia the density of the aponeuroses that bound the femoral ring and the upper edge of the saphenous opening adds to the evil effects of constriction of the hernia, which are also intensified by the congestion of its contents due to the sharp angle made by the sac as it presses forward upon the thigh. The constriction may be due to pressure against Hey's ligament (page 636), Poupart's ligament, or Gimbernat's ligament. The relations of the neck of the sac to the obturator artery (page 814), which once in three and a half cases arises from the epigastric and in two-fifths of such cases passes across the femoral ring (Fig. 1498) or close to its inner border, should be recalled in performing herniotomy. About a half-inch above and to the outer side of the ring lie the deep epigastric vessels; the femoral vein lies externally; beneath the ring the pectineus fibres covering the bone are often so thin that not enough room can be obtained by incision, which is therefore made upward and a little inward, and preferably with a blunted knife that may divide the tense aponeurosis without damage to the vessels which, when they are present, lie in loose cellular tissue a twelfth to a sixth of an inch from the edge of the ring.

FIG. 1498.



Dissection of part of left half of pelvis and adjacent body-wall, showing obturator artery arising from deep epigastric and crossing femoral ring.

Umbilical hernia is most conveniently divided from either a clinical or an anatomical stand-point into the *congenital* and the *acquired* forms. A *congenital umbilical hernia* (*hernia funiculi umbilicalis*) is the result of a defect of development, the anterior abdominal wall failing to close in the region of the navel. Analogous malformations—harelip, spina bifida, vesical exstrophy—sometimes coexist. In addition to intestine, other abdominal viscera may be found in the hernial contents; and in marked cases the condition resembles an eventration (fissura abdominalis) rather than a hernia. Indeed, in some of its forms, the congenital variety is not a true hernia, for "we are not concerned with viscera escaped from a cavity, but with viscera which have never entered it" (Malgaigne).

In the lesser cases the gut—possibly Meckel's diverticulum (*q.v.*)—protrudes into the substance of the cord, separating the structures (page 53) and covered by a layer of embryonic tissue (the jelly of Wharton) and by the amniotic tissue continuous with the skin. A thin avascular membrane directly continuous with the parietal peritoneum is sometimes present. These layers are rarely separately demonstrable, and are often so thin as to be transparent.

In the cases in which only a very small knuckle of gut or a diverticulum is involved (hernia at the root of the cord) there may be merely thickening or enlarge-

ment at that point. If this is overlooked and the cord is tied within the limits of this enlargement, the intestine, if not previously replaced, may be included.

Acquired Umbilical Hernia.—Usually, although the cord is tied at a short distance from the abdominal wall, the stump separates on a level with the latter on account of the contraction of the elastic fibrous tissue around the umbilicus. This cuts off the urachus and the vessels passing through the ring,—the two allantoic or hypogastric arteries and the umbilical vein. Viewed from within, the fibrous cords representing these obliterated vessels would be seen converging to the puckered umbilical scar, the vein from above, the urachus and the arteries from below. As the usual contraction of fibrous tissue takes place, and as the abdomen grows, the traction of these cords depresses the umbilicus so that anteriorly it lies a little below the surrounding surface of the abdomen. The larger amount of tissue represented by the urachus and the two arteries and their close attachment to the lower edge cause that portion of the umbilicus to become the stronger, the umbilical vein being less closely connected to the upper edge of the ring.

In *infantile umbilical hernia* these changes are not complete, but when a knuckle of gut protrudes through the umbilicus during infancy, as a result of increased intra-abdominal pressure, it usually escapes between the vein and the upper margin of the ring on account of their loose attachment. The *coverings* are peritoneum, transversalis fascia, and skin. These herniæ are usually small, and are often cured spontaneously by the contraction of the umbilical and periumbilical scar tissue. Their occurrence is favored by tight phimosis or by constipation, causing straining, or by improper feeding, causing flatulence. After infancy umbilical hernia is rare until adult life.

The umbilical hernia of *adults* is far more common in women than in men (73 per cent.), and is especially favored by obesity—with accumulation of fat in the omentum and mesentery—and by repeated pregnancies. The *coverings* of such a hernia are peritoneum, transversalis fascia, superficial fascia, the fibrous tissue of the umbilical scar and the linea alba, and skin.

For the reasons above given, it appears usually at the upper semicircumference of the umbilical ring and often involves the linea alba immediately above it,—a form of ventral hernia. Such herniæ are very apt to contain omentum—the growth of fat in which often makes them irreducible—and portions of the colon, and, on account of the readiness with which fecal obstruction may be caused in the large intestine, they are prone to incarceration.

Ventral herniæ protrude through the abdominal parietes at other points than the umbilicus or groin, or than those weakened by the passage of vessels and nerves from within outward.

The most common are in the linea alba, between the umbilicus and a point midway between it and the ensiform cartilage (*epigastric hernia*). Above that they are very rare, as the effect of gravity is lacking and the contiguous viscera are less mobile. Immediately below the umbilicus they are not uncommon, as the linea alba has still an appreciable width. Lower, where it has become a mere raphe, they are very rare. They are often associated with subserous lipomata, and may be caused by them. The protrusion of fat from the subserous tissue is thought to draw the peritoneum out into a diverticulum which readily becomes a hernial pouch when intra-abdominal pressure is great enough.

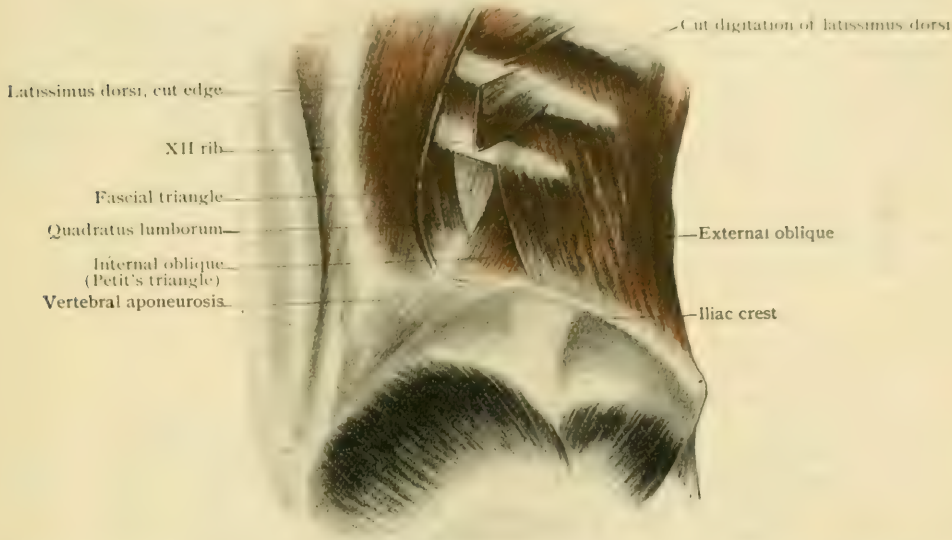
The *linea semilunaris*, especially below the level of the umbilicus, is a not uncommon site of ventral herniæ. It has been suggested that their position is determined by the fold of Douglas (page 522), — the semilunar lower margin of the posterior layer of the internal oblique aponeurosis, which fuses with the transversalis aponeurosis to form the posterior sheath of the rectus muscle, which ends about half-way between the umbilicus and the pubes. Below that all the aponeuroses pass in front of the rectus, leaving the posterior surface of the inferior portion of that muscle separated from the abdominal contents only by the transversalis fascia and peritoneum.

Ventral hernia of the linea semilunaris near its lowest portion and direct hernia issuing through the internal inguinal fossa (page 1770) are indistinguishable, if not practically identical.

Lumbar hernia undoubtedly occurs most frequently in the space known as Petit's triangle (Fig. 1499, page 530), although its protrusion through that space has not been demonstrated by exact dissection.

Above Petit's triangle is another triangular space,—Grynfelt and Lesshaft's

FIG. 1499.



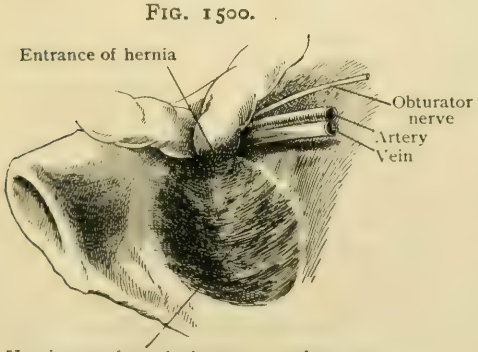
Dissection of postero-lateral abdominal wall, showing fascial (Grynfelt and Lesshaft's) triangle; posterior boundary of Petit's triangle has been cut away.

triangle,—bounded posteriorly by the quadratus lumborum, anteriorly by the internal oblique, and above by the twelfth rib. When the latissimus dorsi is turned aside here it covers only the aponeurotic origin of the transversalis (Fig. 1499).

Braun has found, at a place just posterior to Petit's triangle, the fibres of the aponeurosis of the latissimus dorsi lacking on both sides in a case in which a lumbar hernia existed on one side.

Obturator hernia escapes through the obturator canal, which runs downward, forward, and inward below the horizontal ramus of the pubes. The internal hernial orifice is at the fissure in the obturator internus muscle which permits of the passage of the vessels and nerve. A hernia starting there passes through the opening between the upper edge of the obturator membrane and the lower surface of the pubic ramus (Fig. 1500), and usually descends between the obturator externus and pectineus muscles to lie beneath the latter muscle and the adductor longus. It is therefore to be looked or felt for below the pubes and the inner end of Poupart's ligament, but at a point both lower and more internal than the site of femoral hernia. The thigh should be flexed, adducted, and rotated outward to relax the pectineus, adductor longus, and obturator externus. As this hernia occurs most frequently in elderly females, it is well to note that the inner orifice of the canal may be felt through the vagina. The narrowness of the canal and the rigidity of the thin pectineus and obturator externus muscles make the nerve-pressure symptoms of this hernia of exceptional diagnostic

FIG. 1500.



Right obturator hernia, seen from within.

value. The obturator nerve, which is in close relation with the vessel and the track of the hernia, supplies the hip- and knee-joints and the adductor muscles and aids in furnishing sensation to the inner side of the thigh as low as the knee, and sometimes to the middle of the leg. Pain in these joints and in that region not otherwise explicable, and especially if associated with intestinal symptoms, should therefore suggest a careful examination of the obturator region.

Sciatic herniæ include all the herniæ that emerge from the pelvis through one or other of the sciatic foramina,—that is, (1) through the great sacro-sciatic foramen alongside of the gluteal artery (above the pyriformis); (2) through the same foramen alongside of the sciatic nerve and artery (below the pyriformis); (3) through the lesser sacro-sciatic foramen (Sultan). They are all very rare. The pelvic fascia forms one of the coverings of the sac. Within the pelvis the hernia is anterior to the pyriformis muscle and sciatic nerve. On entering the thigh the sac crosses over the nerve to its posterior surface, and is covered by the gluteus maximus. As the rupture enlarges, it emerges from beneath the lower border of the gluteus and descends the thigh, or may pass forward above the trochanter towards the groin.

When the hernia is small and makes no obvious swelling in the buttock, it is found at the spot where the sciatic artery is tied just outside the pelvis. A line is drawn from the posterior superior iliac spine to the trochanter major rotated inward, and about half an inch below the junction of the upper with the middle third of this line the hernia enters the buttock (Macready).

Perineal herniæ include those which pass through the outlet of the pelvis and its muscular floor. The boundaries of the former are the glutei maximi and coccyx posteriorly, the pubo-ischiatic arch anteriorly, and the great sacro-sciatic ligaments connecting the coccyx and the tuberosities of the ischium (Fig. 1423). The coccygeus and levator ani muscles form the floor of this space, which is perforated by the rectum and urethra and vagina, and extends from the outer walls of these structures to the inner walls of the pelvis (Fig. 1424). It might be supposed that the comparatively yielding nature of the parts which close the lower opening of the pelvis would favor the production of herniæ, but, as Macready has shown, hernia through muscular planes is everywhere very infrequent. The normal oblique inclination of the pelvic floor and its elasticity are doubtless factors in preventing the occurrence of perineal herniæ. A hernia starting at the upper surface of the pelvic diaphragm must pass between the coccygeus and levator ani or between the fibres of the latter muscle, and will descend into the ischio-rectal space (Fig. 1423), where it may cause a protrusion of the skin of the perineum, or may advance towards the rectum (*rectal hernia*), the vagina (*vaginal hernia*), or the posterior portion of the labium majus (*pudendal hernia*).

The development of perineal hernia is believed by Ebner to depend upon an abnormally low descent of the recto-uterine peritoneal fold which occupies Douglas's pouch in the female or of the recto-vesical fold in the male. In the presence of such a fold, intra-abdominal pressure is able to carry a peritoneal pouch, with or without included intestinal coils, to the right or left (its progress in the mid-line being arrested by the firm septum between the rectum and vagina or the rectum and urethra), so that it rests on the levator ani muscle, the fibres of which are often separated at places (Henle describes it as three muscles). Its subsequent downward progress has been noted (*vide supra*).

A form of perineal hernia known as *inguino-perineal* has been described (Coley) in which the hernial sac accompanied—or followed—the misplaced testicle (ectopia perinæalis) into the perineum.

Diaphragmatic herniæ are usually congenital and due to defective development of the diaphragm. A review of the anatomy of that muscle, with special reference to its various openings and to the fissures between its sternal and costal and costal and lumbar portions (Fig. 549), will explain the occurrence of hernial orifices in certain situations, already detailed in connection with hernia of the stomach (page 1632).

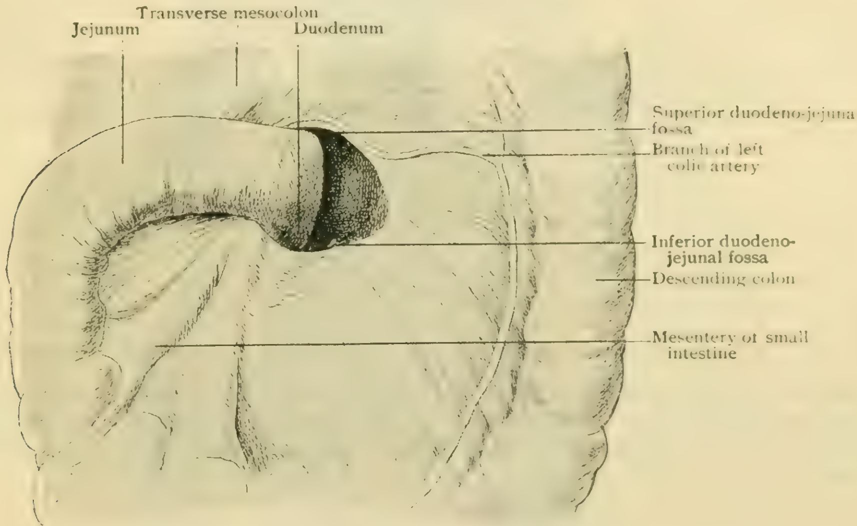
The symptoms are largely those due to gastric disturbance (when the stomach is involved) and to alteration in physical signs caused by compression and displacement of the heart and lungs.

Internal (**intra-abdominal, retroperitoneal**) **herniæ** are those which arise within the abdominal cavity, whether they develop in normal peritoneal recesses or in abnormal peritoneal recesses arising in a physiological manner (Brosike). The classification adopted by Sultan is sufficiently comprehensive to include all herniæ coming under the above definition. Five varieties can be differentiated: (1) hernia of the foramen of Winslow, (2) hernia of the duodeno-jejunal recess, (3) hernia of the retrocæcal and ileo-cæcal recesses, (4) hernia of the intersigmoid recess, (5) retrovesical hernia.

1. The hernia of the foramen of Winslow (Fig. 1475)—into the lesser peritoneal cavity, which may be regarded as a pre-existing hernial sac—is rare on account of the narrowness of the opening (page 1746), and Merkel believes that either an abnormally long mesentery or a retardation of the normal process of fixation of the colon must exist if portions of the intestine are present in the lesser peritoneal cavity. The part of the bowel involved is usually the colon.

2. The duodeno-jejunal fossa, the orifice of which looks upward (Fig. 1501), is formed by a peritoneal fold and is usually to the left of the spine at the duodeno-jejunal junction. It may, in marked cases, receive the whole of the small intestine

FIG. 1501.



Duodeno-jejunal junction, showing duodenal fossæ; jejunum turned to the right.

which is then placed behind the posterior parietal peritoneum. The duodenum can be seen to enter the sac and the end of the ileum to leave it. The renal artery is behind the sac and the inferior mesenteric artery in front of it (Treves). The inferior mesenteric vein and sometimes the colica sinistra artery run in the upper margin of the orifice.

3. The more important peritoneal fossæ about the cæcum are shown in Fig. 1502. They contain herniæ with great rarity; the retrocæcal pocket—extending upward behind the cæcum and ascending colon—has received coils of the lower ileum.

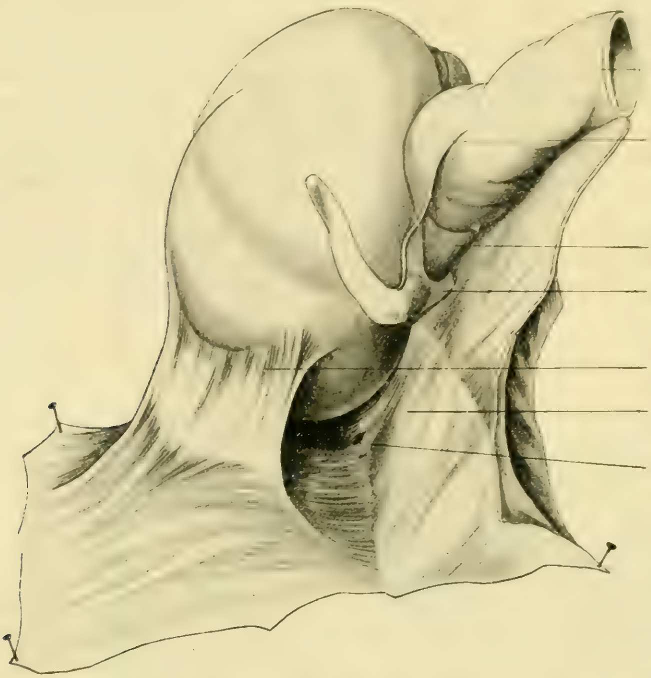
4. By raising the sigmoid flexure and drawing it to the left, the intersigmoid fossa may be seen opening towards the left between the root of the sigmoid meso-colon and the parietal peritoneum. It is caused by the sigmoid artery, and is about over the bifurcation of the iliac vessels. It has been occupied by coils of small intestine.

5. The plica hypogastrica (*ligamentum umbilicalis lateralis*) (Fig. 1487) may be so exceptionally salient as to form a deep peritoneal pocket becoming a retrovesical hernial pouch.

All these internal herniæ have in common the essentials of abdominal herniæ of all varieties,—viz., an orifice through which, by intra-abdominal pressure or by

gravity, or by their own vermicular movement, intestines may be forced into a cavity or space either actually or potentially pre-existing, in which, under lessened pressure as compared with that at the orifice, the bulk of the hernia may increase, with the

FIG. 1502.



Peritoneal fossæ of ileo-cæcal region, cæcum being drawn forward and upward. (*Jonnesco*).

constant danger of incarceration (stoppage of the fecal current) or strangulation (cutting off the supply of blood). The symptoms of internal herniæ are therefore always those of intestinal disturbances and very often those of complete intestinal obstruction.

ACCESSORY ORGANS OF NUTRITION.

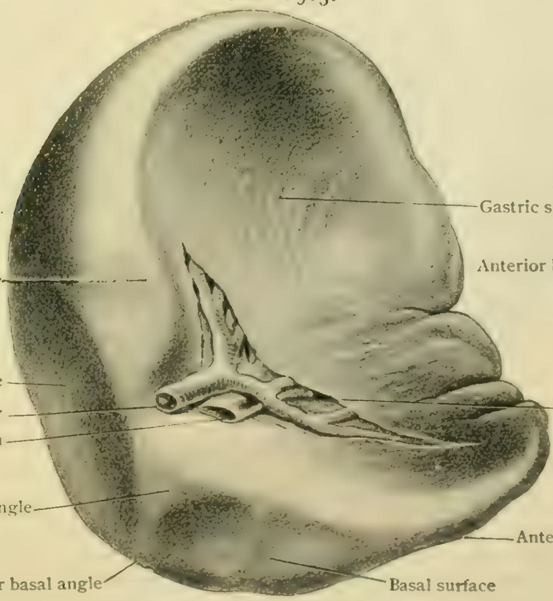
In this group may be included the *spleen*, the *thyroid body*, the *parathyroids*, the *thymus body*, the *suprarenal capsules*, and the *anterior lobe* of the *pituitary body*.

These are sometimes called the "ductless glands," but, as several of them are certainly not glands, the name is unfortunate. To certain members of the above group, as the thyroid and suprarenal bodies, the designation "organs of internal secretion" may appropriately be applied. Considered morphologically, they do not belong to any one system; but on the whole it may be said without grave error that they are concerned in nutrition, and that disease of several of them manifests itself by certain tolerably well-defined symptoms indicating a serious disturbance of nutrition, differing according to the organ involved.

THE SPLEEN.

The spleen is essentially a lymphatic organ. It is of a purplish color and of very friable structure, and is situated in the left hypochondrium behind the stomach. The weight is excessively variable, changing with the state of digestion, and liable to immense increase in certain diseases, as well as to slighter modifications in others. Sappey gives the average weight in ten men as 195 gm. (approximately 7 oz.). The specific gravity is variously stated between 1037 and 1060. The length according to Sappey, in the same ten men was 12.3 cm. (4⅞ in.).

FIG. 1503.



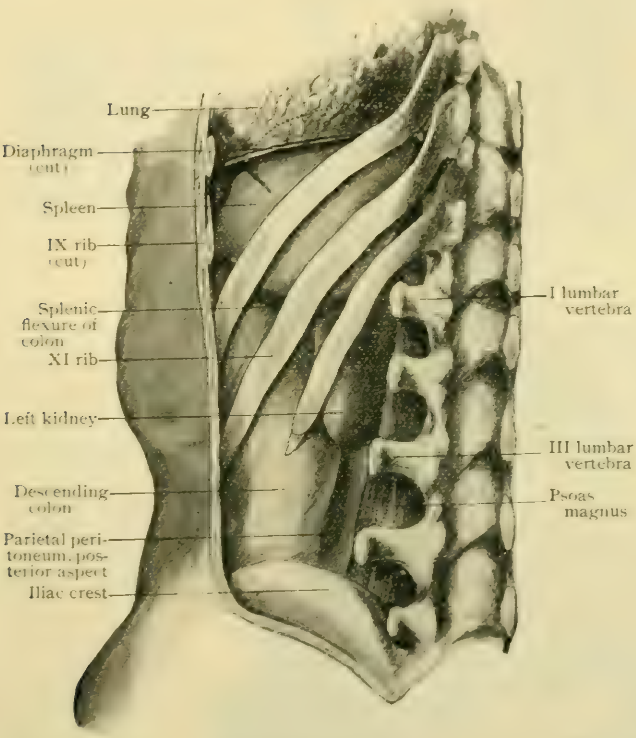
Visceral aspect of spleen hardened *in situ*.

The **shape** of this delicate organ can be correctly understood only after methods of hardening *in situ*. It depends so essentially on the neighboring viscera that what may be the most usual arrangement of several details still remains to be determined. We follow Cunningham in describing a triangular *basal surface* at the lower end, although it is by no means always to be recognized. Besides this there are three distinct surfaces,—the *phrenic*, the *renal*, and the *gastric*,—all of which meet at a rounded point at the top of the organ.

The **phrenic surface** is convex. It is the largest and gives the general outline of the organ. It lies against the diaphragm in the left hypochondrium. The

outline of this surface is that of a lozenge enclosed by an anterior and a posterior border, one point being above and behind, the other below and in front. Thus in the main the long axis corresponds to the course of the lower ribs, which sometimes make impressions on this convex surface. The *anterior border*, formerly the *margo crenatus*, separating this surface from the gastric, is sharp, especially below. It shows one or more notches in 93 per cent.[1] of the cases. They are most common in the lower part of the border, which is sometimes quite scalloped. The *posterior border*, formerly the *margo obtusus*, separating the phrenic surface from the renal, is much less prominent. Parsons found notches in it in 32 per cent.; but the general appearance of this border is very different from the preceding, being in the main solid and uniform. The phrenic surface occasionally (20 per cent.) presents a sharp fissure, rarely more than one. It usually starts from a notch in the posterior border and runs some distance across this surface, forward and upward. Less frequently it starts from the anterior border, or lies entirely in the convexity, reaching neither border.

FIG. 1504.



Postero-lateral wall of formalin subject has been removed to show relations of spleen hardened *in situ*.

The **renal surface**, facing inward, does not extend so high as the preceding. It is enclosed by the posterior border, the *internal* or *intermediate border*, which separates it from the gastric surface, and by one side of the basal surface. In the upper third this surface is nearly plane, resting against the suprarenal capsule, and in the lower two-thirds distinctly concave, where it is moulded over the upper part of the left kidney. The end of the pancreas, if that organ be short, may rest against the anterior part of this surface.

The **gastric surface**, considerably larger than the preceding, is bounded by the intermediate and anterior borders and, below, by another side of the base. It is concave, being for the most part moulded over the stomach. It contains the *hilum*, a fissure some inch and a half long, running parallel to the intermediate border and about one-half inch distant from it, which receives the vessels. The part of this surface which is not against the stomach is at the lower end, and rests against the splenic flexure of the colon. In some cases, when the stomach is contracted and the colon distended, the relative areas of the two may be reversed. Moreover, the omentum may reach the spleen between them. The tail of the pancreas may touch the right part of this surface or, if long, lie against the spleen just above the colon.

The **basal surface** is a triangular area, much smaller than the other surfaces. It is enclosed by the lower part of the posterior border of the spleen and by two lines diverging from the lower end of the intermediate border. One of these separates the basal surface from the gastric and the other from the renal surface. One or both of these lines may be so rudimentary that the base may seem a part of either the

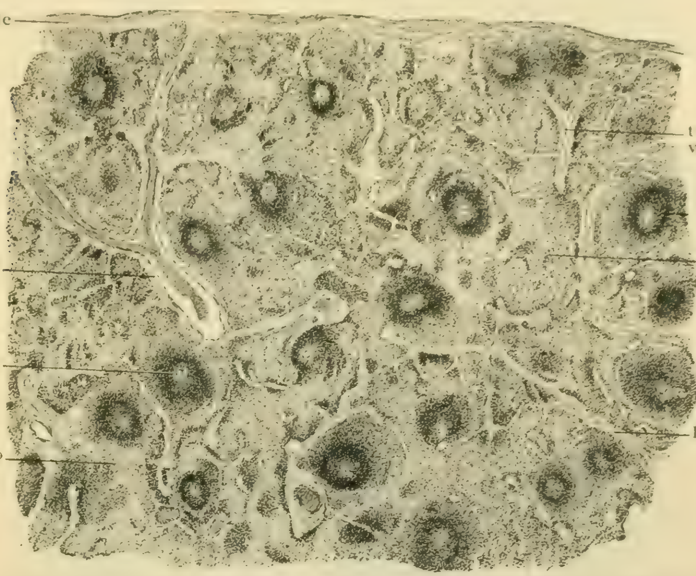
[1] Parsons: Journal of Anatomy and Physiology, vol. xxxv., 1901.

gastric or renal surface, more often the former, or it may appear simply as a knob at the inner side of the lower end. This knob, the *inferior tubercle*, is usually more or less evident at the termination of the intermediate border.

Structure.—In addition to the serous covering contributed by the peritoneum, the spleen is completely invested by a distinct *capsule*, or *tunica albuginea*, composed of dense bundles of fibrous tissue, numerous elastic fibres, and, in its deeper layer, sparsely distributed bundles of involuntary muscle. At the hilum the tissue of the capsule is continued into the organ, supporting the blood-vessels and nerves. The capsule likewise gives off numerous trabeculæ which pass into the substance of the gland and break up into innumerable delicate processes which unite to form the supporting framework.

Mall[1] has shown that this framework is arranged with greater regularity than was formerly recognized, since the trabeculæ subdivide the spleen into fairly regular compartments, the *splenic lobules*, measuring about 1 mm. in diameter. Each of these units is bounded by three *interlobular trabeculæ*, from which secondary *intralobular processes* penetrate into the lobule, whereby the latter is subdivided into about ten *primary compartments*. These, as well as the lobules themselves, are not isolated,

FIG. 1505.



Section of spleen under very low magnification, showing general arrangement of splenic tissue. × 10.

but freely communicate, since the intervening trabeculæ form only incomplete partitions. The spaces within the fibrous framework are filled with the highly vascular lymphoid tissue constituting the *splenic pulp*.

The relation of the blood-vessels to the lobules of the spleen is, according to Mall, very definite. The branches of the splenic artery, after entering at the hilum and running for some distance within the trabeculæ, break up into smaller vessels, each of which enters the proximal end of the lobule, through the middle of which it passes, giving off lateral twigs, one for each primary compartment of the lobule. The lymphoid tissue occupying the compartment is arranged as anastomosing cylindrical masses, the *pulp-cords*. Within the latter course the terminal branches of the splenic arteries, while outside and between the cords lies the plexus of venous spaces from which the more definite channels, the *intralobular veins*, arise. The terminal arteries within the pulp-cords give off numerous small branches which terminate in minute expansions, the *ampullæ of Thoma*. The latter communicate with the venous spaces surrounding the pulp-cords, so that finely divided substances, such as metallic

[1] Johns Hopkins Hospital Bulletin, 1898; Zeitschrift f. Morphol. u. Anthropol., Bd. ii., 1900.

pigments, when injected into the arteries, pass into the veins. The walls of the ampullæ are very thin and, towards the junction with the venous radicles, imperfect, being here composed of the reticulum of the surrounding pulp-tissue. The channels, however, are sufficiently definite to prevent the escape of the blood-cells under normal conditions, although the plasma constantly passes into the intercellular spaces of the pulp (Mall). The walls of the venous spaces are even more pervious than those of the ampullæ, and, like the latter, possess only an incomplete endothelial lining, supported externally by a mesh of circularly disposed elastic fibres. The endothelium consists of narrow, elongated spindle-cells instead of the usual plate-like elements which line the larger splenic blood-vessels. The round or oval nuclei project into the lumen of the venous space beyond the level of the protoplasm of the cell, which often presents a distinct striation.

The venous spaces between the pulp-cords are the beginnings of more definite channels, the *intralobular veins*, which pass from the primary compartments towards

FIG. 1506.

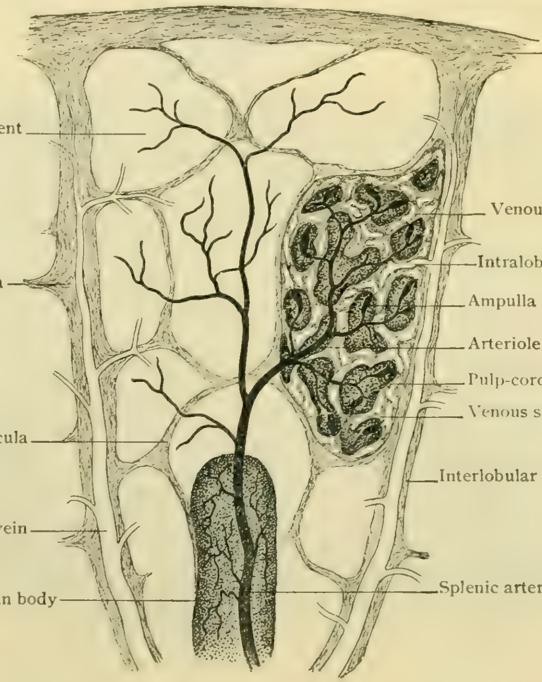


Diagram showing architecture of splenic unit; splenic pulp is represented in only one compartment. (*After Mall.*)

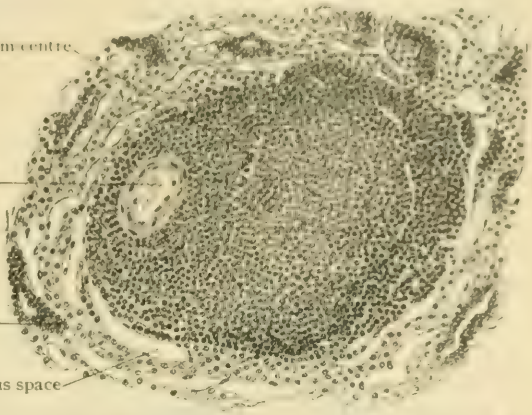
the trabeculæ between the lobules to become tributaries of the larger *interlobular veins* occupying the periphery of the lobules within the boundary septa. These veins follow the larger trabeculæ until, finally, they emerge at the hilum to form the splenic vein.

In their journey through the lobule, shortly after leaving the trabeculæ, the branches of the splenic artery present marked local accumulations of lymphoid tissue within their adventitia. These aggregations constitute the *Malpighian bodies*, or *splenic nodules*. When seen in transverse section, they appear as conspicuous oval areas of dense lymph-tissue surrounding the artery, which usually occupies a somewhat eccentric position. Longitudinally sectioned, the splenic nodules appear as cylinders. They correspond in structure with true lymph-nodes, possessing germ-centres. Surrounding the Malpighian bodies, the spleen-tissue presents the usual arrangement of the pulp-cords.

The **splenic pulp** consists of a delicate supporting *reticulum*, continuous with the terminal ramifications of the intralobular trabeculæ, and the cells contained within

and supported by the mesh-work. The *pulp-cells* include a variety of elements, the most constant of which are: (*a*) small mononuclear lymphocytes; (*b*) leucocytes of the mononuclear and polymorphonuclear types; (*c*) red blood-cells; (*d*) nucleated red blood-cells; (*e*) large phagocytic cells containing disintegrating red blood-cells, or pigment particles derived from the destruction of the same; (*f*) giant-cells with large composite nuclei, chiefly in young animals. In addition a variable amount of free pigment is present, probably from the broken-down red blood-cells. During embryonic life and later, in response to unusual demands for additional red blood-cells, as after severe hemorrhage, the spleen may be the birthplace of red corpuscles; these are at first nucleated, but soon lose their nuclei.

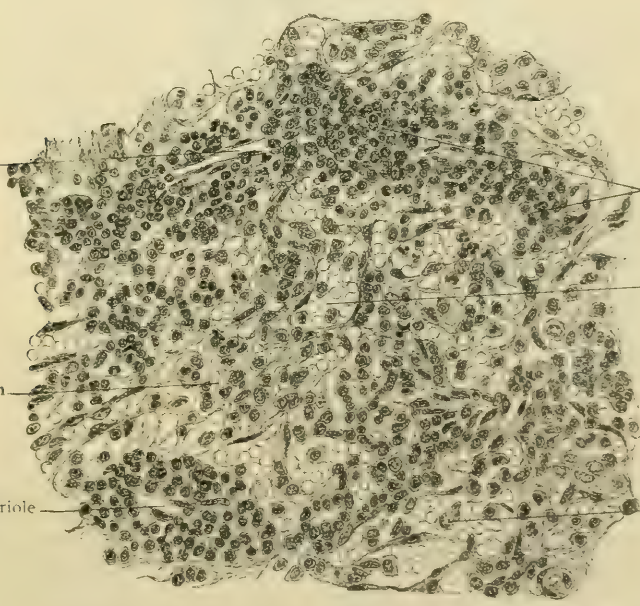
FIG. 1507.



Transverse section of Malpighian body, showing its relations to surrounding pulp-tissue. × 120.

Peritoneal Relations.—The spleen is developed in the posterior mesogastrium, and usually retains all, or nearly all, of its original serous covering, which is reflected at the hilum over the vessels. The splenic artery reaches the spleen through the peritoneal duplicature known as the *lieno-renal* or *lieno-phrenic fold*, which leaves the abdominal wall at the tail of the pancreas. The vessels for the stomach leave the artery before it enters the spleen by the fold known as the *gastro-splenic omentum*, which extends forward to the greater curvature and above to the back of the fundus of the stomach. These two folds, stretching respectively backward and forward from the hilum, bound a part of the lesser cavity of the peritoneum.

FIG. 1508.

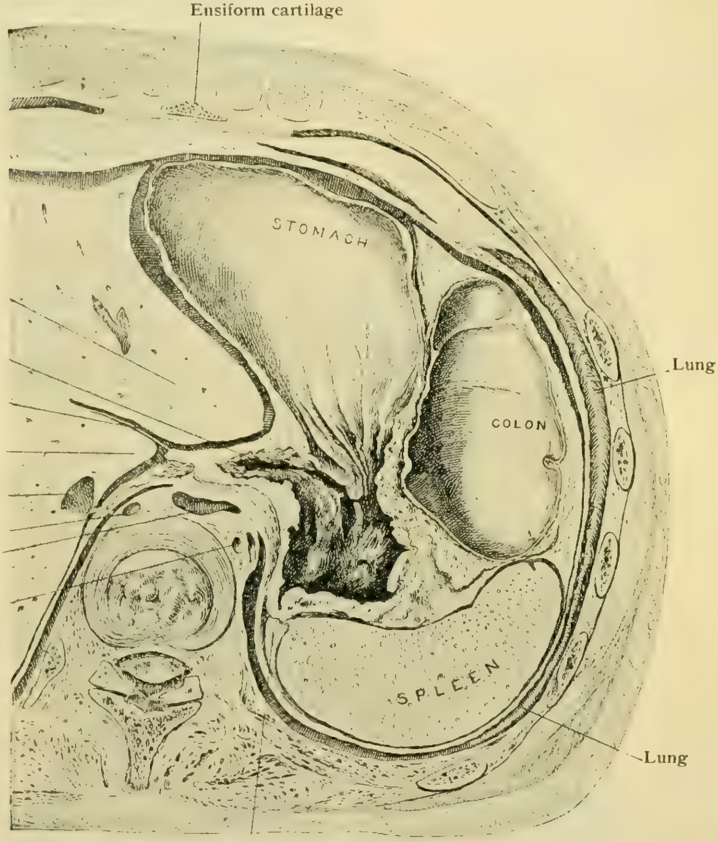


Section of spleen, showing details of pulp-tissue. × 300.

The *suspensory ligament* of the spleen is an inconstant fold belonging to the lieno-phrenic ligament, extending from near the œsophageal opening in the diaphragm to the top of the spleen. It contains connective tissue between its layers, which connects a triangular retroperitoneal area of the spleen with the diaphragm. The *phreno-colic ligament* is a shelf-like fold, derived from the greater omentum, stretched with its free edge forward from the abdominal wall in the region of the eleventh rib to the transverse colon so as to form the floor of a niche in which the spleen rests.

The Vessels.—*The Arteries.*—The splenic artery is a large, tortuous vessel, a branch of the cœliac axis. It is remarkable not only for its large size in proportion to the organ, but for the thickness of its walls. About an inch from the spleen it breaks up into six or more branches which enter the hilum one above another, in

FIG. 1509.



Left half of frozen section across body at level of eleventh thoracic intervertebral disk; under side of section.

the main anterior to the veins, with which they travel along the fibrous walls of the interior. No arterial branch has any anastomosis with the others. Soon after its origin the splenic artery gives off a branch which runs above the main trunk, supplies some twigs to the stomach, and, breaking up into smaller branches, enters the spleen near the top.[1]

The *veins* ramify in the spleen in company with the arteries, and leave it in about the same number of branches, which unite to form the splenic vein behind and below the artery,

The *lymphatics* are chiefly deep ones emerging from the hilum, but there are

[1] Haberer: Archiv für Anat. und Phys., Anat. Abtheil., 1902.

also a few superficial ones. They empty into a little group of lymph nodes at the tail of the pancreas.

The **nerves**, from the solar plexus, enter the hilum with the vessels.

Development and Growth.—The splenic anlage appears about the fifth week of fœtal life as a slight condensation of the mesoblastic tissue of the mesogastrium, associated with local thickening of the mesothelium clothing the left surface of this serous fold. According to Tonkoff,[1] the mesoblast is invaded by migrating cells from the mesothelium, which play an important rôle in the production of the pulp-cords, the trabeculæ resulting from the differentiation of the vascular mesoblastic tissue. The Malpighian bodies appear relatively late as accumulations of young lymphocytes.

At birth the spleen weighs from 10–15 gm., and is said to be relatively rather large. In the fœtus accessory spleens are found very frequently along the course of the splenic vessels. On the other hand, Parsons seems to find the surface of the spleen more regular than in later life. The fissures on the convex surface are less frequent and less deep. The great size of the liver in the fœtus brings the left lobe into contact with the spleen. The relatively large suprarenal capsule nearly or quite separates it from the left kidney.

Accessory spleens[2] are common, but they are not all of the same significance. Some are constricted parts of the spleen which have become separated, mostly from the anterior border, and are connected with the organ only by fibrous tissue. Others, found chiefly in the greater omentum near the hilum, are apparently distinct masses of splenic tissue. Many of them, however, have no Malpighian corpuscles, are intermediate between the spleen and the lymph-nodes, and, probably, are to be classed as hæmolymph-glands. They are said to be found sometimes within the pancreas. It is not impossible that certain irregular nodules occasionally found on the spleen near the hilum are due to the fusion of such accessory spleens. Otto has seen twenty-three accessory spleens in one body. They are usually of the size of a pea.

Surface Anatomy.—The relations of the spleen to other organs have been described, but it should be stated that the phrenic surface lies beneath the ninth, tenth, and eleventh ribs (sometimes the eighth also), and that its long axis is that of the shafts of these ribs. It is important to note that the spleen is situated behind the stomach rather than to the left of it, so that in general language the organ is more in the back than in the flank. The highest level of the spleen is opposite the body of the ninth thoracic vertebra, and its lowest opposite that of the first or second lumbar. A line from the top of the sternum to the tip of the eleventh rib should be entirely anterior to the spleen.

PRACTICAL CONSIDERATIONS: THE SPLEEN.

The spleen may be congenitally absent, or it may be of extremely small size,—no larger than a walnut; or there may be *supernumerary* spleens connected with the main gland; or there may be *multiple* spleens entirely separate and lying in the folds of the greater omentum, the gastro-splenic omentum, or the transverse mesocolon. It is conceivable but unlikely that these anomalies may lead to mistaken diagnoses.

The outline of the normal spleen is difficult of accurate determination by either palpation or percussion because (*a*) it is covered in front by the stomach, the cardiac end of which—if the stomach is distended—completely overlaps it; (*b*) posteriorly it is covered at its lower portion by the diaphragm and by the tenth and eleventh ribs and the thick muscles overlying them, and at its upper portion by the same muscles, the diaphragm, the ninth rib, the pleura, and the lung; (*c*) inferiorly it is in contact internally with the upper end and part of the outer edge of the left kidney, and externally with the splenic flexure of the colon; (*d*) the upper part of the phrenic surface is occasionally in contact with the left lobe of the liver (Quain); (*e*) it is the most variable in both shape and size of all the abdominal viscera; (*f*) it

[1] Archiv f. mikro. Anat., Bd. lvi., 1900.
[2] Consult articles by Parsons and by Haberer, just noted.

changes in position with the movements of the stomach, having its longest diameter vertical when the latter is contracted and horizontal when it is distended.

These relations sufficiently explain the difficulty not only in determining the size of the normal spleen, but also in distinguishing by percussion its abnormal enlargement from cases of colonic fecal impaction, of tumors of the left kidney, of large plastic exudate at the base of the left pleura or lung, of hypertrophic cirrhosis involving the left lobe of the liver, and of certain growths of the stomach or omentum.

In cases of hypertrophy or of swelling of the spleen, as in malaria ("ague-cake"), palpation is often of more value than percussion, the sharp crenated anterior border being recognizable below the tenth costal cartilage. Physiological increase in size occurs during digestion, but pathological enlargement may follow portal congestion, leukæmia, malaria, typhoid, or other infectious disease, including most forms of general sepsis, or may result from infection of the splenic substance. It may—as in some malarial and leukæmic cases—so enlarge as to occupy most of the abdominal cavity. It is then closely applied to the parietes, and is not, like renal tumors, covered anteriorly by the intestines.

Enlargement of the spleen in infants is often due to inherited syphilis, and if it occurs at the age of two or three months is usually of that character. It is of more diagnostic value than enlargement of the liver, because that organ is normally disproportionately large in infancy, and because other causes than congenital syphilis lead to its enlargement.

In all forms of enlargement of the spleen in children there is said to be more relative encroachment upon the thoracic cavity than in adults, owing to the firmer support of the phreno-colic ligament in young persons (Treves). Whenever it is greatly enlarged, at any age, it is apt to push upward the diaphragm and compress injuriously the base of the left lung and the heart. In splenic tumors, therefore, irregular cardiac action and dyspnœa are often present for mechanical reasons as well as on account of the associated anæmia.

The normal movements of the spleen are not so much affected by respiration as are those of the liver, which is more closely and extensively connected with the diaphragm. It rises slightly in expiration and descends during inspiration. It is pushed down in emphysema and in left-sided empyema, hæmothorax, or pneumothorax. It is pushed up by ascites or by intra-abdominal new growths.

Its relations explain why *abscesses* of the spleen (usually due to septic emboli, as in pyæmia or septicæmia, typhoid fever, or ulcerative endocarditis) open spontaneously in the following directions: (1) Into the general peritoneal cavity (the most frequent). (2) On the cutaneous surface below the costal margin anteriorly or posteriorly. (3) Into the large intestine. (4) Into the left pleural cavity. (5) Into the left kidney.

Movable spleen (*dislocated*, *floating*, *wandering spleen*) occurs only in adults, and is especially found associated with some degree of splenic enlargement—increasing its weight—in persons with relaxed or flabby abdominal walls. It is, therefore, often found in anæmic multiparæ, as it is held in position normally not only by the phreno-splenic and phreno-colic ligaments, but also by the pressure of the other abdominal viscera due to the general tonicity of the abdominal muscles.

In such cases, after elongation of the phreno-splenic ligament, the spleen falls forward, lies horizontally with the hilum directed upward, and is sustained only by the gastro-splenic attachments and the vessels, thus drawing the stomach downward and causing serious gastro-intestinal disturbance, or possibly, if the vessels are twisted and obliterated, a fatal peritonitis (Shattuck).

In exceptional cases a movable spleen may reach the pelvis.

From a movable kidney a wandering spleen may be distinguished by the superficial position of the latter, its shape, the disappearance of the spleen from its normal position, and the absence of urinary symptoms.

Wounds of the spleen, if posterior, usually involve the diaphragm and the base of the left pleural cavity, or, if higher, the lung itself; if anterior, the stomach may be penetrated. In gunshot wounds the kidney, colon, or pancreas may likewise be involved.

In fractures of the ninth, tenth, or eleventh rib the fragments may lacerate the spleen. On account of its great vascularity, wounds of the spleen are serious and often necessitate operation, but occasionally, after small stab wounds or gunshot wounds from bullets of small calibre, spontaneous recovery takes place, and has been attributed (Treves) to the contractility of the muscular tissue of the splenic capsule, which narrows the wound-track, enables it to retain the blood-clot, and thus stops the hemorrhage.

The blood from a wound of the spleen is usually bright red. In wounds of the liver it is apt to be dark, if the lung is wounded the blood is commonly frothy, and if the stomach has been penetrated the blood is mixed with the acid gastric contents.

Rupture of the normal spleen is not very frequent, in spite of its friability, on account of the way in which it is suspended from the diaphragm, supported beneath by the elastic colon and—indirectly—the small intestine, and partially protected anteriorly by the stomach and posteriorly by the lung. When it is enlarged, on the contrary, it extends beyond the region of safety, becomes more closely and extensively applied to the parietes, and may be ruptured by blows, by falls from a height, or even by muscular violence. Spontaneous rupture can occur only in cases of advanced hypertrophy with softening of the parenchyma. The latter may be ruptured, but the elastic capsule escape. In all these cases of splenic injury the symptoms of localized intra-abdominal lesion, pain, often at first general, then referred to the epigastrium or umbilicus, then more marked in the splenic area, sometimes accompanied by nausea or vomiting and followed by rigidity of the left upper quadrant of the abdomen, immobility of the lower thorax on that side, meteorism, etc., plus the symptoms of internal hemorrhage, will be present to a greater or less degree. They have been sufficiently explained in the sections on the intestine, the appendix, and the peritoneum.

In *operations* on the spleen it may be approached through incision either at the outer edge of the left rectus muscle or in the median line.

In *splenectomy* great care must be taken to avoid premature tearing or division of the large vessels contained within the gastro-splenic omentum and lieno-renal ligament, particularly the splenic vein. The "pedicle"—omentum and vessels—may sometimes best be reached by lifting the inner border of the spleen, and sometimes (Warren) by pulling the spleen down from beneath the diaphragm and turning it completely over.

Next to hemorrhage, the chief risk is that arising from damage to adjoining viscera during the separation of adhesions, and the relations of the stomach, pancreas, colon, and kidney should therefore be carefully borne in mind.

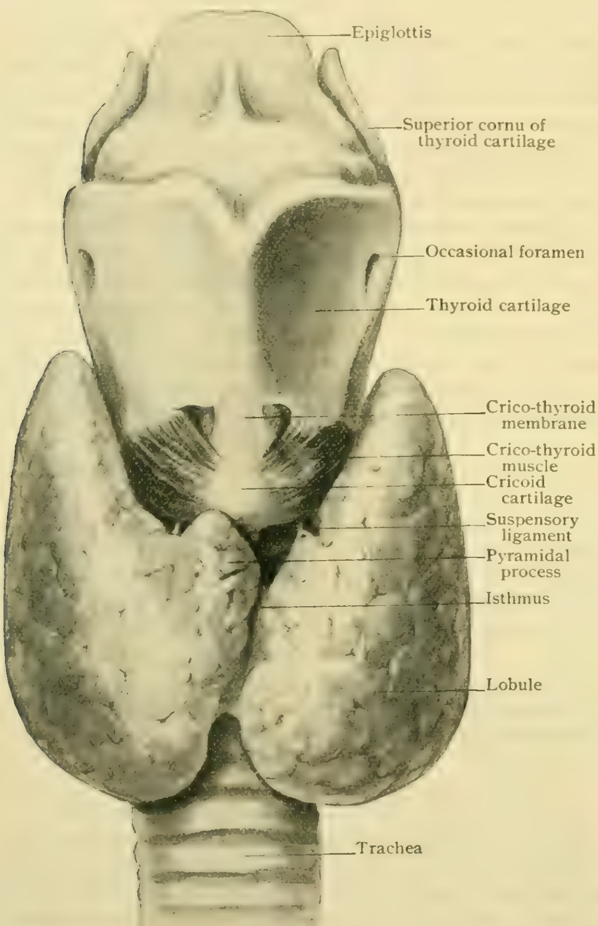
THE THYROID BODY.

This organ is situated in the neck in front and at the sides of the trachea. It is symmetrical in plan, but not usually in the details, consisting of two *lateral lobes* connected by a narrow strip, the *isthmus*, from 5 mm. to 2 cm. in breadth. The height of the lateral lobes ranges from 3 cm., or less, to twice as much within normal limits. The transverse diameter of the whole organ is 6 or 7 cm. The weight is from 30–40 gm. (1–1½ oz.), with wide variations. It has the appearance of a lobulated glandular body, reddish yellow in color.

Shape and Relations.—Each lateral lobe is an irregular body, vaguely pyramidal in form, which can be properly studied only *in situ*. There is an *antero-external surface* which meets the inner at a sharp border. The *inner surface* is concave, being moulded over the side of the trachea and larynx. These surfaces are connected by a third, the *posterior surface* (usually improperly called a border), which faces backward and outward, sometimes nearly backward. The surfaces come together above in an apex over the posterior part of the body, so that the border separating the antero-external and the internal surfaces rises from the middle of the body obliquely backward. The lower end of the lateral lobe is thick and rounded. The *isthmus*, connecting the lateral lobes below the middle, usually crosses the second and third rings of the trachea. Its anterior surface passes without interruption into the

antero-external surfaces of the lateral lobes. The isthmus varies much in size, and is often more or less incorporated in one of the lobes. In 10 per cent. it is absent.[1] An upward projection, the *pyramidal process*, rising from either the isthmus or one of the lateral lobes, and usually regarded as a remnant of the median anlage of the thyroid, is found more or less developed in probably half the cases. A typical one reaches the hyoid bone, to the body of which the process is generally attached either by muscle or ligament. It is rarely quite median, being more frequently found on the left. Statements as to its frequency vary greatly. Streckeisen[2] says it is wholly wanting in only about 20 per cent.; but, since goitre is common in Switzerland, his sources of information are not of the best. Zuckerkandl, however, puts the occurrence of the process at 74 per cent. Gruber, in Russia, found it in only 40 per cent., and Marshall, in England, in 43 per cent. We incline to believe that these latter figures represent the more common proportion.

FIG. 1510.



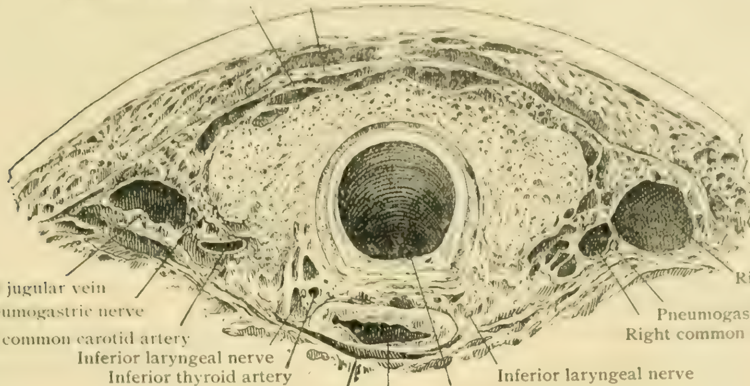
Thyroid body *in situ*; anterior aspect.

The thyroid lies beneath the group of infrahyoid muscles, from which it is separated by the middle layer of the cervical fascia. The sternomastoid muscle crosses the lower part of the lateral lobes. The inner surface lies against the trachea, the cricoid cartilage, and the lower posterior part of the wings of the thyroid cartilage. It reaches back to the œsophagus, which it touches on the left, and sometimes on the right also. It may touch the lower part of the pharynx on both sides. The sheath of the carotid lies against the posterior surface at its outer border and is in part external to the organ. The common carotid is usually behind the thyroid and the internal jugular vein beyond it. This explains how an enlarged gland insinuates itself between these vessels. Frozen sections show that often the carotid is external rather than posterior to the organ, but still in close relation to it. Internal to the carotid sheath, it rests behind against the prevertebral fascia. The inferior thyroid arteries enter the lateral lobes from the inner side and the superior thyroid arteries from the antero-external. The middle cervical sympathetic ganglion is behind. The inferior laryngeal nerves lie at its inner surface, the left one being in actual contact with the thyroid and the right one at least very close to it. The sheath connects the thyroid body very closely to neighboring parts. It is so firmly bound to the trachea as to follow its movements. Median bands to the cricoid and thyroid cartilages have been

[1] Marshall: Journal of Anatomy and Physiology, vol. xxix., 1895.
[2] Virchow's Archiv, Bd. ciii., 1886.

distinguished as *suspensory ligaments*. A *lateral ligament* from the inner side of the lateral lobe is tolerably well defined. It passes backward and upward to the first ring of the trachea, to the cricoid, and perhaps to the inferior horn of the thyroid. The *levator glandulæ thyroideæ* is a small muscle often found passing down from the hyoid bone to the capsule. It may or may not be connected with the pyramidal process.

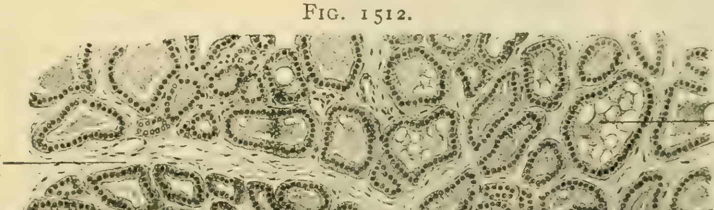
FIG. 1511.



Anterior part of frozen section across neck, showing relations of thyroid body.

Structure.—Although in principle corresponding in its development with other compound alveolar glands, the thyroid body possesses no excretory ducts and presents peculiarities in the structure of its terminal compartments. The fibro-elastic *capsule* investing the gland gives off septa which subdivide the organ into the chief lobules, the latter being composed of smaller compartments separated by thin partitions of connective tissue. These subdivisions, or *primary lobules*, from .5–1 mm.

FIG. 1512.



Section of thyroid body, showing acini in various degrees of distention. × 100.

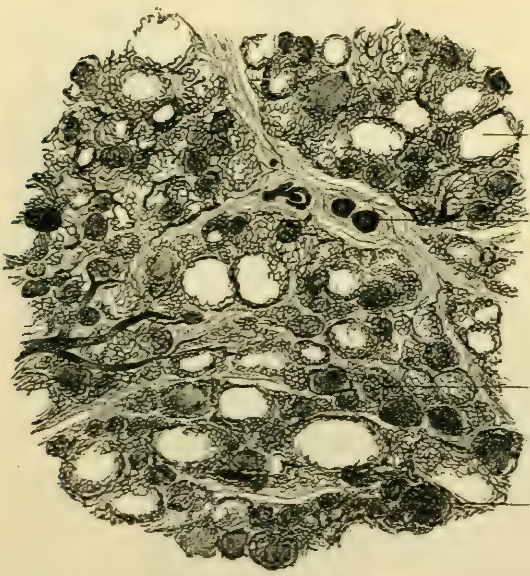
in diameter, contain a variable and usually large number of terminal vesicles or follicles which correspond to the alveoli or acini of ordinary glands. The delicate and highly vascular framework supporting the follicles consists essentially of fibrous connective tissue, elastic fibres being few or entirely absent.

The *acini* vary greatly in size (.050–.200 mm.), depending upon the amount

of secretion and the distention of the acini. Their lining consists of a single layer of fairly regular polygonal cells, about .010 mm. in diameter, the height of the cells varying with the dilatation of the follicle. In young subjects, in whom the acini are generally less completely filled than in older ones, the epithelium of the follicles approaches the columnar type. A similar condition is often to be noted in certain acini, even in thyroids in which the usual distention affects the majority of follicles. A distinct basement membrane is wanting, the cells resting directly upon a somewhat condensed stratum of the surrounding connective tissue. Since the epithelial lining is the source of the peculiar colloid secretion of the gland, the cells ordinarily contain a variable number of highly refracting granules, particularly in the zone next the sac. The peculiar substance or *colloid* commonly found within the follicles of the adult organ is regarded as a proteid, although its exact chemical characteristics are still uncertain. The consistence of this substance varies, being more fluid in young than in old glands. Its varying appearance within the follicles, as vacuolated, reticular, or shrunken, is referable to the action of reagents, in its natural condition the secretion being homogeneous and entirely filling the follicle. The differentiation of the epithelial lining of the acini into chief and colloid cells (Langendorff), as representing distinct elements, is doubtful, since specific differences probably do not exist.

Vessels.—The blood-supply is very generous, coming from two pairs of relatively large *arteries*, the superior thyroids from the external carotids, and the inferior thyroids from the subclavians. The superior descend to the top of the lateral lobes and ramify over the front of the organ, sending branches to the interior, and sometimes meeting on the isthmus. The inferior arteries pass upward behind and enter the organ on its inner surface. Their relations to the inferior laryngeal nerve are of practical importance. In 437 observations[1] the artery was found in front of the nerve on the right in about 41 per cent. and on the left in 63 per cent. In over 10 per cent. of the cases the branches were so interlaced that the relation was uncertain. It is evident that in enlargement of the thyroid body, with consequent enlargement of the arteries, the number of such indefinite relations would be very much increased, as very minute branches would then spring into importance. An enlarged tortuous artery tends to curl around the nerve. There was no artery on the right in one case and none on the left in five cases of this series. An *arteria thyroidea ima* springing from the arch of the aorta and ascending in the median line is occasionally seen. From the rich superficial arterial plexus numerous branches pass along the interlobular septa, following the ramifications of the latter to the follicles, where the arterioles break up into capillaries. These surround the follicles with close-meshed net-works, which are often common to the adjacent sacs, resembling the capillary net-works around the pulmonary alveoli.

FIG. 1513.



Section of injected thyroid body. × 46.

The *veins* are very numerous. Emerging from the organ, they form a large

[1] Dwight: Anatom. Anzeiger, Bd. x., 1895.

plexus beneath the capsule, from which the blood escapes by three chief courses on each side. The superior thyroid veins are double, and follow the artery to open either into the internal jugular directly or into the facial. They may communicate with the linguals. The middle thyroid vein, less regular, passes from the side of the lobe into the internal jugular, anastomosing, as a rule, with the pharyngeal venous plexus. The inferior thyroid veins, generally two in number, some 5 mm. in diameter, come from the deeper part of the organ and form a rich plexus in front of the trachea under the middle layer of the cervical fascia, draining, for the most part, into the left innominate; but a vein may end at the angle of the two innominate veins. The inferior thyroid veins can be injected from below.

The *lymphatics* begin within the organ as perifollicular lymph-spaces; from these plexuses follow the interlobular septa in their course to the exterior, where they constitute a superficial plexus from which the lymph passes in all directions. Some run upward from the isthmus to small lymph-nodes in front of the larynx, some from the sides to the deep glands about the internal jugular, and some from the isthmus and adjacent parts downward to pretracheal lymph-nodes.

The **nerves** are derived, for the most part, from the cervical sympathetic. It is probable that filaments are contributed by sympathetic fibres running in company with the inferior laryngeal and the hypoglossal nerves. In addition to the fibres destined for the walls of the blood-vessels, the terminal twigs end around the follicles in close relation with the glandular epithelium.

Development.—The thyroid is developed from an unpaired median anlage. This anlage, irregular in form and size, (Fig. 1521), appears in embryos of from 3-4 mm. as an epithelial outgrowth from the anterior wall of the primitive pharynx in the region of the second visceral arch, and therefore in close relation with the posterior part of the tongue. At first possessed of a narrow lumen, the evagination soon loses its cavity and becomes a solid pyriform mass, which for a short time is connected with the pharyngeal wall by a delicate epithelial strand. Usually the latter soon disappears and the isolated median anlage, which meanwhile rapidly increases as a bilobed mass, passes to the lower level of the early thyroid. The position of the primary outgrowth is later indicated by the depression on the tongue, the *foramen cæcum*, just behind the apex of the V-row of the circumvallate papillæ. Occasionally the evagination persists, and then forms the *thyro-glossal duct*, a narrow tube extending for a variable distance from the tongue towards the thyroid body. The epithelial outgrowth, which, on either side, appears on the ventral wall of the fourth pharyngeal furrow, was formerly known as the lateral thyroid anlage, under the belief that it contributed to the formation of the lateral lobe of the thyroid gland. Later studies have shown, however, that this is not the case, the outgrowths in question usually disappearing, or giving rise to small masses resembling thymic tissue. Mention may be made of a pair of outgrowths from the floor of the primitive pharynx where the fifth furrow would be. These are the *ultimo-branchial bodies*, which usually degenerate and disappear.

The histogenesis of the thyroid includes two stages, the first being distinguished by numerous cylindrical epithelial cords from which grow out lateral branches. The second stage witnesses the fusion of these epithelial cords into a net-work the meshes of which are occupied by vascular mesoblastic tissue. During the third fœtal month the epithelial reticulum breaks up into masses corresponding to the follicles of the thyroid. These gradually acquire a lumen around which the cells become arranged to constitute the epithelial lining of the compartments in which later the characteristic colloid substance is secreted. The thyroid agrees with the parathyroids and the thymus in originating from the walls of the primitive pharnyx and, likewise, in deviating in its later development from its primary correspondence to a typical gland.

Accessory Thyroids.—Small detached bodies of the same structure as the thyroid are occasionally found about the hyoid bone in the median line, both before and behind and sometimes below it. They are remnants of the median thyroid diverticulum from the primitive pharynx, sometimes represented by the thyro-glossal duct. This passed originally in front of the hyoid bone, thus accounting for suprahyoid and prehyoid accessory thyroids. Those behind and below the hyoid are probably the result of an upward or downward growth from the primary diverticulum.

PRACTICAL CONSIDERATIONS: THE THYROID BODY

Congenital absence of the thyroid body, or its atrophy with loss of function, occurring at any time before puberty, is apt to be followed by the interference with nutrition and with normal mental and physical development that produces the condition known as *cretinism*. Similar atrophic changes occurring later in life cause *myxœdema*, and the same condition—also known as *cachexia strumipriva*—may be brought about by the complete excision of the gland. Calcification of the gland may take place in old age. The isthmus may be congenitally absent and two separate lobes be present, representing the originally distinct embryonic lateral anlages of the organ.

Accessory thyroids may undergo hypertrophy and form large masses occupying the pleural or the mediastinal cavity (Osler-Packard); or they may develop at the base of the tongue,—lingual goitre; or, on account of their embryonic relation to the thyro-glossal duct (which passes behind the hyoid bone), they may be found in the median line of the neck below or behind the hyoid, and may be mistaken for growths of a different character (page 554).

The thyroid gland may be temporarily enlarged in women during menstruation.

Hypertrophy of the thyroid gland (goitre) may be (*a*) *parenchymatous* when it results from a general hyperplasia of the gland-tissue; (*b*) *vascular*, due to a great increase in the size and number of the blood-vessels; (*c*) *cystic*, characterized by the formation of walled-off cavities within the already enlarged gland; (*d*) *fibrinous*, the connective-tissue elements being in excess; (*e*) *exophthalmic* (Graves's disease), in which the thyroid enlargement is associated with exophthalmos and functional derangement of the vascular system; (*f*) *adenomatous*, the hypertrophy affecting one or more lobules or the isthmus. This last form appears as a one-sided or asymmetrical swelling, is common, and is often classified with tumors of the thyroid, rarer forms of which are the cancerous and sarcomatous. It may be noted that the gland is relatively larger in females, and that the right lobe is larger than the left. This has been thought to explain the greater frequency of goitre on the right side, and in women.

Inflammation of the thyroid is rare, and usually occurs during typhoid or other infections, although it is favored by previous thyroid disease or overgrowth. The tumefaction which it produces may cause acutely many of the symptoms brought on more slowly by the chronic forms of enlargement. These symptoms, so far as they have any anatomical bearing, are: (1) *The swelling rises and falls with the larynx during deglutition.* This is due to the attachment of the thyroid gland to the cricoid cartilage by the upward prolongations of its capsule known as the suspensory ligaments and to the subjacent larynx and trachea by connective tissue. (2) *Dyspnœa.* The gland is covered and its growth anteriorly resisted by the sterno-hyoid and sterno-thyroid muscles (Fig. 545), and, to a less degree, by the omo-hyoid and the anterior border of the sterno-mastoid. Its forward progress is also resisted by the pretracheal layer of the cervical fascia. Its close relation to the trachea, therefore, renders the latter subject to direct pressure, especially in the firmer forms of bilateral enlargement, or in those adenomata which begin in the isthmus or lie between the trachea and the sternum. In the unilateral forms the trachea may be displaced to one side. (3) *Headache*, *vertigo*, *cyanosis*, and *epistaxis*. The relation of the outer border of the thyroid to the carotid sheath explains the disturbance of the circulation in the carotid and internal jugular (either through direct pressure or by deflection of the vessels outward) and accounts for these phenomena. (4) *Dysphagia* is relatively rare, but may occur as the result of pressure upon the upper end of the gullet or the lower portion of the pharynx. It is more common in left-sided goitres, owing to the curvation of the œsophagus towards the left. As a great rarity the isthmus of the gland is found between the trachea and œsophagus (Burns). (5) *Dysphonia*, or *aphonia*, due to pressure upon the recurrent laryngeal nerves. (6) *Pulsation* or *bruit*. These may be apparent, and caused by the close relation of the enlargement to the common carotid artery, or—much more rarely—real, and due to the relatively enormous blood-supply of the vascular form of goitre, the thyroid with its four constant arteries and occasional fifth one (the thyroidea ima,—10 per

cent. of cases) being normally one of the most vascular structures of the body. They are most common in the exophthalmic form. (7) The *tremor*, *tachycardia*, and *protrusion of the eyeballs* seen in Graves's disease in association with thyroid enlargement have no satisfactory anatomical explanation, although the close relation of the sympathetic nerve and middle cervical sympathetic ganglion to the inferior thyroid artery, the distribution of their vasomotor fibres to the thyroid vessels, and of other associated fibres to the ocular apparatus, and their possible central connection—"probably in the medulla" (Treves)—have been invoked to explain the phenomena of this form of goitre.

Operations on thyroid enlargements vary with the character of the latter.

In the adenomatous and cystic varieties, after division of the capsule of the gland, the tumor or the cyst may generally be shelled out with the finger or by blunt dissection (enucleation). Under these circumstances only some superficial veins may require ligation, although free bleeding may occur from the intrinsic vessels of the gland. In most of the other varieties of goitre the greater part of the growth should be removed (excision, thyroidectomy). This should always be partial,—*i.e.*, a portion of the gland should be left in place with sufficient vascular connection to insure its vitality.

In excision the skin platysma and cervical fascia should be freely divided and the sterno-hyoids and thyroids retracted or divided; after its anterior surface has been well exposed the growth is first loosened externally,—as it will be found fixed above by the superior thyroid vessels, below by the inferior thyroids, and internally by the isthmus,—the vessels separately ligated, great care being taken to avoid the recurrent laryngeal nerve when the ligature is applied to the inferior thyroid artery, the posterior surface dissected from the larynx, trachea, and other underlying structures, and the growth removed.

THE PARATHYROID BODIES.

These organs, the *epithelial bodies* of many authors, are small elliptical masses situated near the thyroid, which formerly were mistaken either for accessory thyroids or for lymphatic nodules. They arise from the posterior wall of the third and fourth pharyngeal pouches, and thus differ from the thyroid body in origin as well as in structure. They are 6 or 7 mm. long, 3 or 4 mm. broad, and 1.5 or 2 mm. thick. The length may be as much as 15 mm. They are always separated from the thyroid by the capsule. Most frequently the parathyroids exist as two pairs on each side; their disposition, however, may be asymmetrical, in some cases as many as four, in others none, lying on one side. The position of the *superior pair* is the more constant and, according to Welsh,[1] corresponds about with the level of the lower edge of the cricoid cartilage. They usually lie against the posterior surface of the lateral thyroid lobes, between the middle and the inner border of this surface. The *inferior pair* is lower and more anterior than the superior, their position being less constant. Sometimes they lie against the side of the trachea near the ends of the rings, under cover of the lower part of the thyroid lobes; sometimes they are found in a corresponding relation to the windpipe, but much lower, so as to have no relation with the thyroid; occasionally they lie on the front of the trachea below the thyroid. The surest means of locating the little bodies are the minute parathyroid arteries, small twigs chiefly from the inferior thyroids, to each one of which a parathyroid body is attached. It is evident, therefore, that these organs may be found on almost any aspect of the thyroid gland.

FIG. 1514.

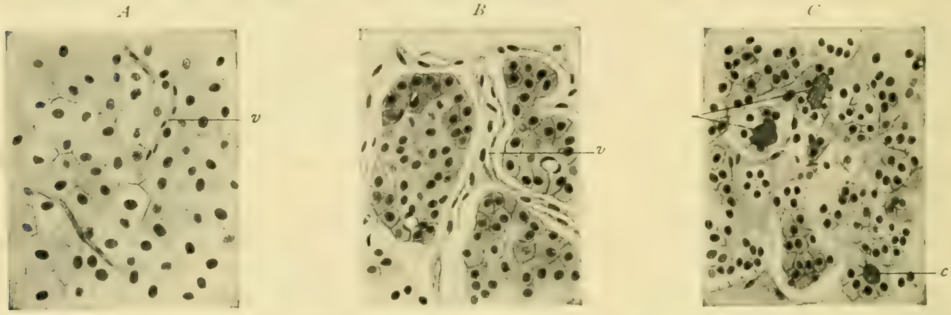
Thyroid and parathyroid bodies viewed from behind; p^1, p^2, right superior and inferior parathyroids; *st*, superior thyroid artery; *a*, anastomosis; *n*, recurrent laryngeal nerve. (*Ginsburg.*)

Structure.—Each organ is invested by a thin fibrous capsule and subdivided into ill-defined lobules by a few delicate septa which support the blood-vessels.

[1] Journal of Anatomy and Physiology, vol. xxxii., 1898.

The gland-tissue consists of closely placed polygonal epithelial cells, about .010 mm. in diameter, varyingly disposed as continuous masses or imperfectly separated cords and alveoli. The cells possess round nuclei which contain chromatin reticula. The cells are surrounded by a honey-comb of delicate membranes, fibrous tissue appearing only in the immediate vicinity of the larger blood-vessels and not between the epithelial elements. The latter lie against the endothelial lining of the relatively wide and numerous capillaries, the attenuated membrane of the intercellular honeycomb alone intervening. While admitting the independence of the parathyroids as

FIG. 1515.



Sections of human parathyroid bodies, showing different types of structure. *A*, principal cells arranged as uniform continuous masses; *B*, broken up into lobules by vascular septa (v); *C*, disposed as acini, some of which contain colloid (c). × 200. (*After Welsh.*)

distinct organs, as now established by both anatomical and physiological investigations,[1] opinions differ as to their histological relations. Schaper[2] and others incline to the view advanced by Sandstroem, that the parathyroids correspond in structure to the immature and undeveloped thyroid. Welsh, on the contrary, denies this resemblance and points out the close similarity to the anterior lobe of the pituitary body, in both organs colloid-containing alveoli being occasionally present.

The arteries distributed to the parathyroids are derived from the branches supplying the thyroid body. Regarding the lymphatics and the nerves little is known; the latter are chiefly sympathetic fibres destined for the walls of the blood-vessels.

THE THYMUS BODY.

The thymus is apparently an organ of service to the nutrition—possibly blood-formation—of the fœtus and infant, since it usually reaches its greatest size at about the end of the second year, having grown since birth fairly in proportion to the body. It continues for some years to enlarge in certain directions and to dwindle in others; coincidently deposits of fat appear and it gradually degenerates. When in its prime it is moderately firm and of a pinkish color; later it becomes very friable and resembles fat and areolar tissue.

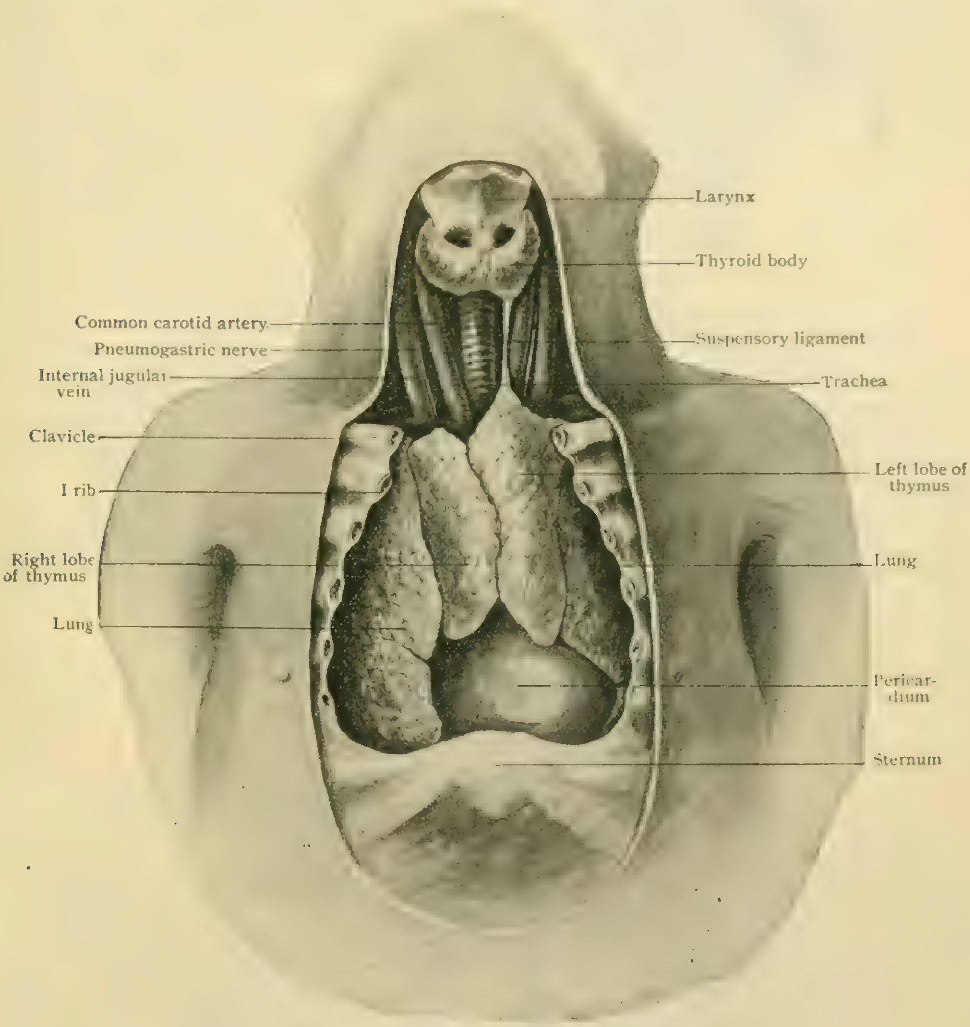
Shape and Relations.—The appearance of the thymus is that of a glandular organ. It is surrounded by a *fibrous capsule* which sends prolongations among the lobules. It is situated beneath the upper part of the sternum, rising, when largest, perhaps 2 cm. into the neck, descending to about the fourth costal cartilages, exceptionally as far as the diaphragm. The organ is thickest above, where it rests on the pericardium, and descends in front of the latter in two flattened lobes, more or less distinct, which grow thinner and sometimes diverge below. These are separated by a layer of fibrous tissue which enters obliquely from the front in such a way that above the left lobe overlaps the other. The lobes are generally of unequal size, the left one being more often the larger. Sometimes the lobes are fused, and there may be a third one between them, such variations merely implying irregularities of the fibrous septa. The thymus lies in front of and above the pericardium, and against

[1] A critical review of the relations of the epithelial organs derived from the pharyngeal pouches is given by Kohn in Merkel and Bonnet's Ergebnisse, Bd. ix., 1899.

[2] Archiv f. mikro. Anat. u. Entwick., Bd. xlvi., 1895.

the aorta and the pulmonary artery after they have emerged from the heart-sac. It is in contact with a large part of the arch of the aorta, and is grooved on the posterior surface by the innominate veins and the superior vena cava. If strongly developed, its highest part may rest on the trachea and even on the œsophagus where this tube appears on the left of the former. It extends laterally on each side into the interval between the pericardium and the pleura. At the time of its greatest size, a horizontal section in this region shows the thymus as a thick crescent (Fig. 1518), which becomes thinner as the organ atrophies. Behind the very top of the sternum its out-

Fig. 1516.



Dissection of new-born child, showing thyroid and thymus bodies *in situ*.

line on section is roughly quadrilateral. One or more fibrous bands from the thyroid body to the capsule of the thymus are known as the *suspensory ligaments*. The internal mammary vessels run in front of it.

Weight and Changes.—According to Friedleben, the average weight of the thymus at birth is 13.75 gm.; the statements of authors, however, vary widely, Sappey giving 3 gm. and Testut, from twenty observations, an average of 5 gm. When heaviest, about puberty according to Hammar, its average weight is 37.52 gm. Atrophy and the replacement of thymus tissue by fat set in while growth in length is still pro-

gressing; this increase is said to continue even after puberty, the organ, however, becoming thinner and softer. Although later almost completely replaced by adipose and connective tissue, the thymus never entirely disappears, remains of its tissue being present even in extreme old age (Waldeyer). Until about twenty years the organ is usually readily found. In ordinary dissections it is not easily recognized in middle age, although still clearly shown in frozen sections. Occasionally a well-preserved thymus persists in the adult; on the other hand, it may suffer atrophy very early in childhood.

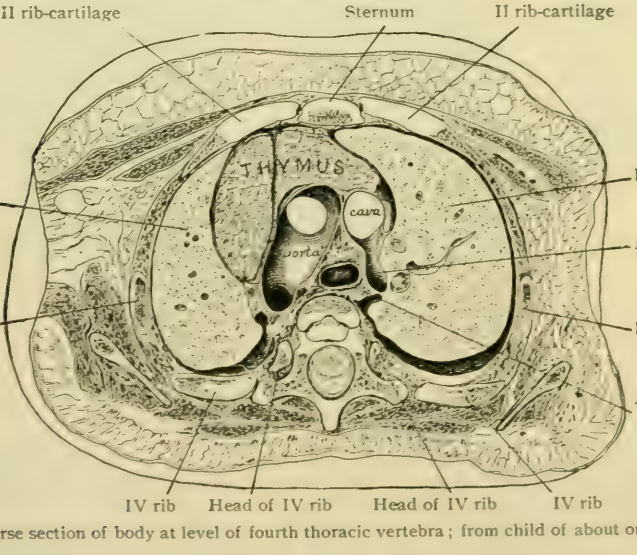
FIG. 1517.

Posterior aspect of thymus body hardened *in situ.*

Structure. — The histological character of the thymus completely changes during its development, since it begins as an epithelial outgrowth from the third pharyngeal pouch, for a time attains the nature of a tubo-alveolar gland, and later permanently assumes the type of a lymphoid organ. Externally the thymus is invested by a loose fibro-elastic *capsule*, from which septa, rich in blood-vessels, pass towards the interior and subdivide the organ into a number of indefinite *lobes*. The latter are broken up into small, almost spherical *lobules*, which correspond to lymph-nodules, and consist, therefore, of a denser cortical and looser medullary zone, although these are not sharply defined from each other.

The *cortical substance* presents histological characteristics resembling those of dense lymphoid tissue,—closely packed lymphocytes lying within the narrow meshes of the supporting reticulum. The latter consists of the stellate reticulum-cells, which

FIG. 1518.



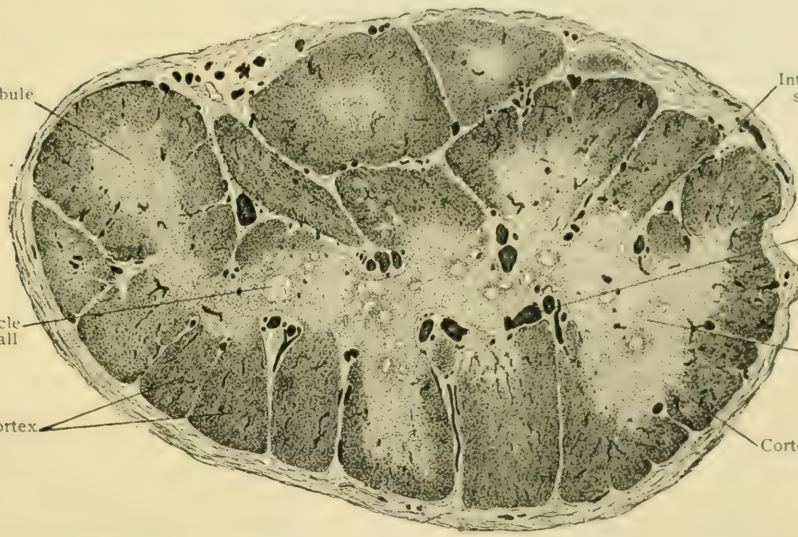
Transverse section of body at level of fourth thoracic vertebra; from child of about one year

are derived from the metamorphosed original entoblastic epithelium. The thymic lymphocytes, on the contrary, are descendants of migratory cells, which early invade the reticulum. In addition to the usual elements, eosinophilic cells are found

throughout the cortex, particularly in the neighborhood of the capillaries. Nucleated red blood-cells have been described within the cortex (J. Schaffer).

The *medullary substance*, although varying in its details according to the general condition of the organ, consists of a supporting framework, composed of branching cells, within the meshes of which lie small mononuclear lymphocytes, less frequently polymorphonuclear leucocytes. Occasional eosinophiles are seen along the blood-vessels, as well as multinuclear giant cells. Islands or cords of flattened elements, regarded by many as epithelial in nature and derivatives of the primary entoblastic anlage, also occur. The medulla of the fully developed thymus, or of the organ just entering upon its retrogression, contains numerous spherical or ellipsoidal masses of concentrically disposed, flattened modified cells. These bodies are the *corpuscles of Hassall*, which were regarded as the direct remains of the epithelium of which for a time the thymus was composed. Found only in the medulla, they vary greatly in form and size, sometimes being simple spherical masses (.012–.020 mm. in diameter), at others composite bodies (.1 mm. or more in diameter) consisting of aggregations of small groups. The centre of the concentric bodies often consists of slightly glistening, homogeneous, or granular substance which is

FIG. 1519.



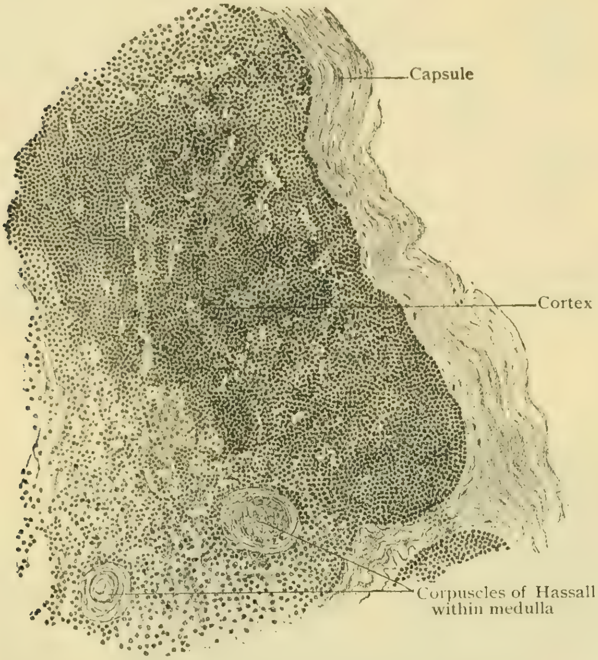
Transverse section of thymus body of child, showing general arrangement of lobules. × 25.

albuminous, not fatty, in nature. According to Hammar, the corpuscles of Hassall arise from hypertrophied reticulum cells, the latter being directly derived from the primary epithelium.

Vessels.—The *arteries* are chiefly from the internal mammaries, but small branches may come from the thyroid as well as from the pericardial arteries. The arteries gain the interior of the lobule, and break up into capillaries along the junction of the cortical and medullary zones. The cortex is provided with a rich capillary net-work, the medulla being relatively poorly supplied. The *veins* between the lobules, which chiefly drain the capillaries, unite to form the larger trunks carrying the blood from the organ. These run in many directions, the most important being tributary to the left innominate. The *lymphatics* are large and numerous, and empty into nodes behind the sternum. Traced into the interior of the organ, the lymphatics follow the connective-tissue septa to the lobules, around which they form a rich plexus. Although it is probable that the lymph-paths come into close relations with the thymus-tissue, the existence of intralobular passages, corresponding to lymph-sinuses, has not been established.

The **nerves** are small and come from the sympathetic and the vagus. They are traceable along the arteries and connective-tissue septa, and end chiefly in the walls of the blood-vessels. Bovero has described terminal filaments which pass from the interlobular plexuses into the medulla.

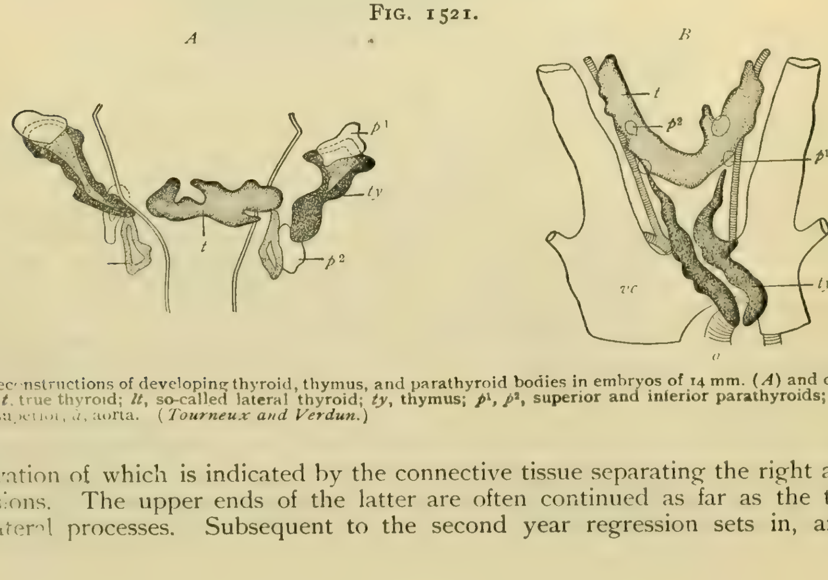
FIG. 1520.



Section of thymus body, showing details of cortical and medullary substance. × 200.

Development. — The thymus proper originates from a paired anlage (Fig. 1521) which appears as an epithelial outgrowth from the ventral wall of the third pharyngeal pouch. From this results a long cylindrical mass of closely packed epithelial cells which grows downward and encloses a narrow lumen. The lower end of this mass increases in size by the formation of solid acinous outgrowths resembling those of an immature tubo-alveolar gland. Coincident with the downward extension of the organ, the upper cylindrical portion gradually assumes the alveolar condition until the entire thymus acquires a lobulated character. During these changes histological alterations take place, the epithelial masses becoming invaded by ingrowing lymphoid tissue and blood-vessels and broken up into irregular islands. The latter become smaller and less conspicuous as the lymphoid character of the thymus becomes more predominant. The corpuscles of Hassall represent derivatives of the primary epithelial elements. For a time the two originally distinct anlages develop independently; later they come into close contact in the mid-line, and form the single irregular organ the bilateral

FIG. 1521.



Reconstructions of developing thyroid, thymus, and parathyroid bodies in embryos of 14 mm. (*A*) and of 26 mm. (*B*). *t*, true thyroid; *lt*, so-called lateral thyroid; *ty*, thymus; p^1, p^2, superior and inferior parathyroids; *vc*, vena cava superior; *a*, aorta. (*Tourneux and Verdun.*)

derivation of which is indicated by the connective tissue separating the right and left divisions. The upper ends of the latter are often continued as far as the thyroid as lateral processes. Subsequent to the second year regression sets in, and the

thymus structure is largely replaced by fibrous and adipose tissue, vestiges of the characteristic tissue, however, persisting (Fig. 1522).

In addition to the chief anlage from the third pharyngeal pouch, a rudimentary outgrowth occurs from the ventral wall of the fourth one. This anlage may persist in man as the *parathymus*, a small body which occurs in close association, or even encloses, the parathyroid derived from the dorsal wall of the fourth pouch. It should be noted that the close association of the thymus and upper parathyroids results in a downward displacement and transposition, so that, eventually, the upper parathyroids come to lie below the original lower outgrowths.

Fig. 1522.

Section of thymus body of man of twenty-eight, showing invasion and replacement of thymus tissue by fat. × 20.

According to Beard, Prenaut, Bell and others, the transformation of the thymus into a lymphoid organ occurs as the direct conversion of its original epithelial elements into lymphocytes and not by invasion of pre-existing lymphoid cells. While accepting such origin for the reticulum, Hammar[1] and Maximow[2] regard the lymphocytes as entering from without.

THE SUPRARENAL BODIES.

These are a pair of cocked-hat-shaped bodies situated at the back of the abdomen, on the inner aspect of the upper ends of the kidneys. Each has a *base*, or *renal* surface, corresponding to the bottom of the hat, and an *anterior* and a *posterior* surface, the basal borders of which are concave and look outward and downward. There are an upper and a lower angle at either end of the base. The inner convex border tends, especially in the right capsule, to present a third angle rather above the middle. Thus the right one is more triangular and the left more crescentic. They may be 6 or 7 cm. long and about half as broad. The thickness does not probably often exceed 2 cm. The *base* is concave, adapted to the kidney, of which it overhangs the anterior surface. The lower end is much thicker than the upper. The concavity deepens above into almost a furrow filled by areolar tissue. The *anterior surface* bears a deep fissure, the *hilum*, in the main parallel with the base, subdividing it into two approximately equal regions. The *posterior surface* is considerably smaller than the anterior, owing to the projection of the latter over the front of the kidney. It also presents a fissure nearly parallel with the base-line, but neither extending the whole length of the organ nor so deep as the front one.

In color the suprarenals are of a dirty yellowish brown and more or less pigmented. They weigh 6 or 7 gm. The left one is usually the larger.

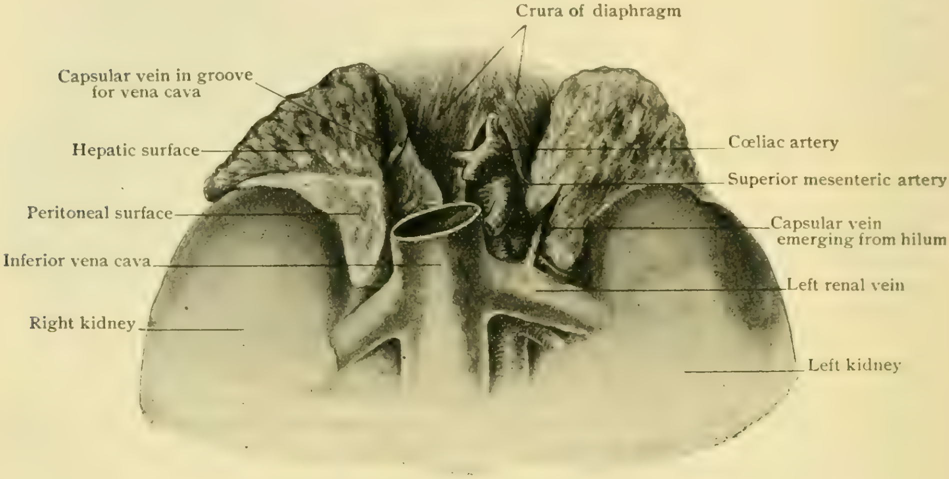
Relations.—The *basal surfaces* are on the kidneys. The *posterior surfaces* are against the diaphragm. The *anterior surface* of the *right* capsule has its lower inner part behind the inferior vena cava. The part of the lower end near this may be behind the duodenum. The remainder is in contact with the liver. The highest

[1] Anatom. Anzeiger, Bd. xxvii., 1905.
[2] Archiv. f. mik. Anat. u. Entwick., Bd. 74, 1909.

part is between the non-peritoneal posterior surface of the liver and the abdominal wall. This, of course, like the two preceding areas, has no peritoneum. The rest lies in contact with the lower surface of the liver, and is coated by the peritoneum of the posterior abdominal wall. The *anterior surface* of the *left* capsule is nearly or quite peritoneal, resting against the stomach, the spleen, and the tail of the pancreas.

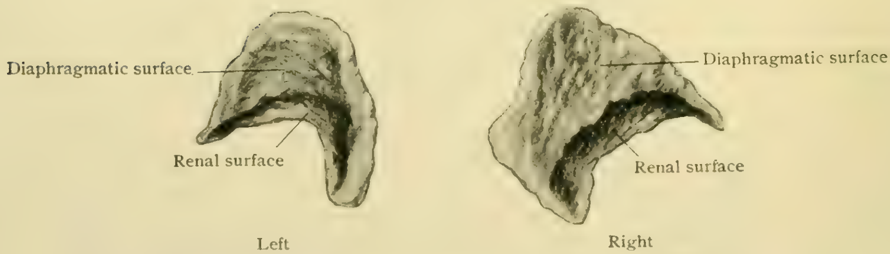
Structure.—The suprarenal body is invested by a thin, but fairly strong, fibrous *capsule*. Section across the thicker parts of the organ displays an outer zone, or *cortex* (.25–1.20 mm. in thickness), which surrounds the central *medulla*. Where thinnest, as towards the borders, the medulla is reduced to a narrow zone and may be entirely wanting; where best developed, as in the middle of the organ, it may attain a thickness of over 3 mm. The cortex is usually of a dirty yellow color, presenting

FIG. 1523.



Anterior aspect of suprarenal bodies hardened *in situ*.

FIG. 1524



Posterior aspect of suprarenal bodies shown in preceding figure.

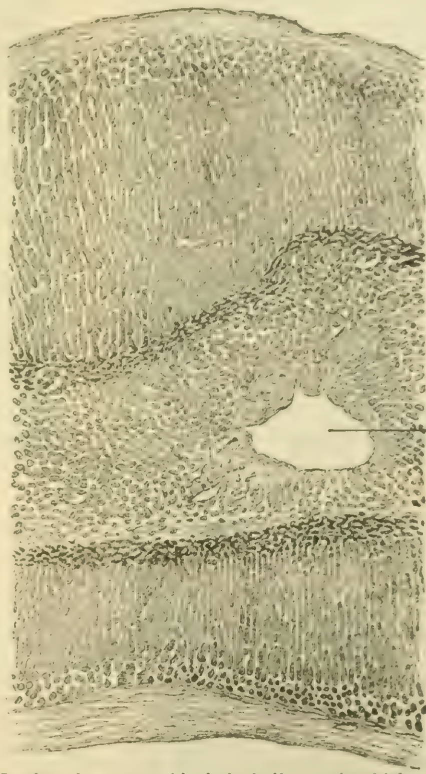
next the medulla a narrow darker zone of varying shades of brown. The medulla is of a grayish tint and generally lighter in color than the cortex. Its exact tint, however, varies with the amount and condition of the contained blood, when engorged with venous blood appearing dark. In consistence the medulla is less resistant and more friable than the cortex.

The *cortical substance* consists of a delicate framework of connective tissue, continuous with and prolonged inward from the capsule, in the meshes of which lies the glandular epithelium. The arrangement of the latter, although generally columnar, varies at different levels, three zones being distinguished within the cortex. The *zona glomerulosa* lies next the capsule, and consists of the somewhat tortuous or coiled groups of cells. The *zona fasciculata* forms the chief part of the cortex, and maintains the radial disposition of the cell-columns. The *zona reticularis*, next the

medulla, includes the net-works of epithelial elements formed by the union of the cylinders. The cells throughout the cortex are very similar, being rounded polygonal elements .015–.020 mm. in diameter, and very often contain fat granules. Those composing the zona fasciculata are largest, while those within the reticular zone are more or less pigmented and responsible for the darker tint of this portion of the cortex.

The *medullary substance* consists chiefly of net-works composed of anastomosing cords of epithelial cells from .020–.036 mm. in diameter; in addition there are numerous blood-vessels, particularly veins, and many bundles of nerve-fibres with ganglion-cells. The protoplasm of the medullary cells is finely granular and possesses an especial affinity for chromic acid and its salts, staining yellow or brown. They vary from polyhedral to columnar in form, and often border large blood- and lymph-spaces. The cells of the medulla are more prone to undergo post-mortem change than those of the cortex.

FIG. 1525.



Section of suprarenal body including entire thickness of organ, showing general arrangement of cortex and medulla. × 27.

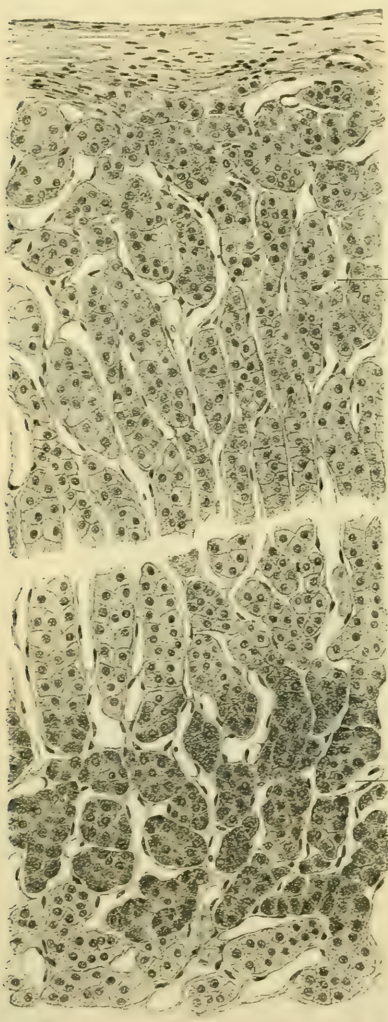
Vessels.—The chief *arteries* supplying the organ are the three suprarenal or capsular arteries,—the middle from the aorta and the superior and inferior from the phrenic and renal arteries respectively. They break up into a dozen or more fine branches before reaching the organ, which they enter at various points, some penetrating directly into the medulla, others terminating in the cortex. The latter form a superficial capillary net-work within the capsule, from which continuations pass between the cortical cell-columns, around which they constitute capillary net-works. The medulla is directly supplied by arteries destined for the interior of the organ. These soon break up into capillaries which surround the medullary cords and pass over into an unusually rich plexus of veins. The latter claim as tributaries the venous radicles of the zona reticularis and impart to the medulla in general a spongy character. The *veins* form a rich plexus about the organ, communicating freely with those of the kidney. The chief vein of the right suprarenal passes into the inferior vena cava and that of the left one into the renal. The *lymphatics* are numerous, the chief trunks accompanying the arteries. In addition to the superficial net-works in the outer part of the cortex, the medulla contains many deeper lymphatics in the vicinity of the larger veins.

Nerves.—The very rich supply is derived principally from the solar and renal plexuses. The number of medullated fibres would imply that many come through the splanchnic nerves. Branches probably come also from the vagus and the phrenic (Bergmann). Within the capsule lies a superficial plexus from which small bundles of nerve-fibres enter the cortex, between the cell-columns of which they form plexuses, chiefly for the walls of the blood-vessels. The greater number of the nerves, however, pass to the medulla, where they unite into coarse plexuses, from which finer twigs are distributed to the vessels and the cords of medullary cells surrounding the veins. Dogiel has traced the terminal filaments between the epithelial elements. Numerous ganglion-cells lie within the medulla. Sometimes they occur in groups along the larger nerve-bundles; at other times they are encountered as isolated ele-

ments; but in all cases they exhibit the characteristics of sympathetic cells. Indeed, so numerous are the latter that the suprarenal is regarded by some anatomists as an organ accessory to the sympathetic nervous system.

Development and Growth.—The genesis of the suprarenal body has been the subject of much discussion and uncertainty, especially as to the origin of the medulla. Comparative and embryological studies clearly indicate that the mammalian suprarenal body consists of two separate and distinct organs, which, although intimately united as cortex and medulla, possess a different origin and function.[1] According to the investigations of Aichel,[2] the suprarenal in the higher mammals first appears in close relation to the Wolffian body, the anlage arising from the proliferation of mesoblastic cells at the ends of invaginations of the mesothelium lining the body-cavity. The individual cell-groups thus arising with the several invaginations fuse into the general anlage of the suprarenal. The primary close association of the latter with the Wolffian body is later lost, the subsequent migration of the organ bringing it into secondary relation with the permanent kidney.

FIG. 1526.



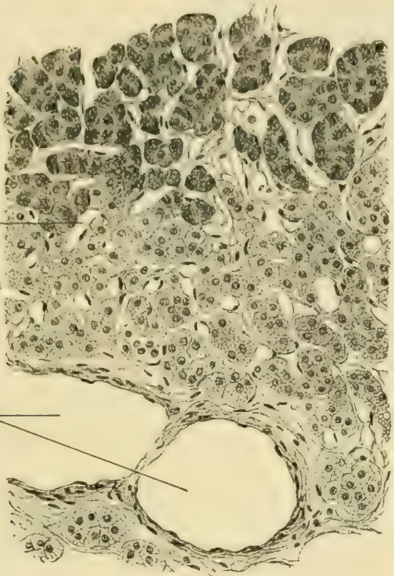
Section of suprarenal body, showing details of superficial and deep portions of cortex. × 225.

Regarding the origin of the medulla two views obtain. According to the one generally accepted, the medullary portions are developed from cells which are derived from the adjacent embryonic sympathetic ganglia, the chief support of this opinion being found in the close correspondence of the medullary cells with the chromaffin elements of sympathetic origin occurring in other localities, such cells wherever found exhibiting an especial affinity for chromium salts. When fully developed, the medullary cells may be regarded as highly specialized cells which elaborate a powerful stimulant that, when injected into the blood, produces increased contraction of the heart-muscle and of the involuntary muscle of the arteries. The other view attributes the origin of the medullary cells to the same mesoblastic anlage that produces the cortical cords. The differentiation of the suprarenal into cortex and medulla occurs comparatively late and long after the primitive organ has become sharply defined from the surrounding tissue. For a time the entire organ consists of cells which are identical in appearance. During the third month this common tissue differentiates into cortex and medulla, in consequence of the breaking up of the outer zone into columnar masses by the advent of connective-tissue trabeculæ from which delicate fibrillæ arise, forming the inner boundary of the cortex. Within the central part of the organ thus defined numerous venous capillaries appear and break up the tissue

[1] Vincent: Journal of Anatomy and Physiology, vol. xxxviii., 1903.
[2] Archiv f. mikro. Anat., Bd. lvi., 1900.

into the cords of medullary cells which lie directly in contact with the endothelium of the veins. The subsequent ingrowth of the nervous constituents provides the unusually rich supply of nerve-fibres and ganglion-cells distinguishing the medulla. These organs are proportionally very large in the fœtus (Fig. 1529). At birth the antero-posterior diameter is 1 cm. and the greatest transverse diameter at the base is 1.5 cm.; the length from the apex to the anterior end of the base is 3.5 cm. and to the posterior end 1.5 cm. At this age the suprarenal covers most of the upper half of the kidney. At an earlier period these organs are markedly lobulated so as closely to resemble the kidneys; at term, however, the lobulation has nearly disappeared.

FIG. 1527.



Section of suprarenal body, showing portions of cortex and medulla. × 225.

FIG. 1528.

Section of injected suprarenal body; the vessels in lower third of figure are chiefly tributaries to the central vein. × 25.

Accessory Suprarenals.—These are mostly very small, rarely surpassing a pea in size. They may be found near the suprarenal body, in the kidney, in the liver, in the solar and renal plexuses, or beside the testis or the ovary. The accessory suprarenal situated within the broad ligament in the vicinity of the ovary is regarded by Marchand and others as a normal and almost constant organ. The latter undergoes compensatory hypertrophy after removal of the chief suprarenal. The investigations of Aichel emphasize that the organs included under the designation "accessory suprarenals" comprise two groups of structures of different origin and morphological significance. Those associated in position with the chief organ, as when in the kidney or liver, are derived from separated and isolated portions of the principal anlage of the suprarenal, and,

FIG. 1529.

Dissection of three months female fœtus, showing huge suprarenals, lobed kidneys, and sexual glands.

therefore, are supernumerary. The bodies, on the contrary, situated within the broad ligament, or in intimate relations with the epididymis, are probably developed from the atrophic tubules of the Wolffian body, and hence must be regarded as independent structures. It is said that the suprarenal bodies are sometimes wanting.

PRACTICAL CONSIDERATIONS: THE SUPRARENAL BODY.

Hemorrhage into the suprarenal body in new-born infants has been observed (post mortem) in a number of cases. Various opinions as to its cause have been expressed. They have been summed up (Hamill) as follows: (1) weakness of the vessel-walls, normal or abnormal; (2) traumatism, especially during labor, from pressure of the hands in making traction in delivery by the lower pole, and from the frictions and flagellations used to resuscitate the apparently dead-born; (3) asphyxia from delay in the establishment of respiration at birth; (4) acute fatty degeneration of the vessel-walls; (5) fatty degeneration of the tissues of the organ; (6) firm contraction of the uterine muscles, the resistance of the parts traversed, and consequent compression of the inferior vena cava between the liver and the vertebral column, thereby producing congestion and hemorrhage into the non-resistant tissues of the suprarenal gland; (7) convulsions; (8) syphilis; (9) central vasomotor influence from cerebral lesions; (10) mechanical squeezing of blood into the part during the process of labor; (11) too early ligation of the cord; (12) arrest of the circulation through the umbilical artery from compression of the cord or separation of the placenta; (13) thrombosis of the renal vein or inferior vena cava; (14) infection.

Hamill concludes that the first of these seems to be the fundamental anatomical element favoring the occurrence of hemorrhage, that in still-born children prolonged and difficult labor is the exciting cause, and that in those dying later some form of infection is responsible.

In cases of *tumor* of the suprarenal body the following symptoms have been noted (Mayo Robson): (*a*) shoulder-tip pain, probably explained by the fact that a small branch of the phrenic nerve passes to the semilunar ganglia; (*b*) pain radiating from the tumor across the abdomen and to the back, not along the genito-crural nerve; (*c*) marked loss of flesh; (*d*) nervous depression with loss of strength; (*e*) digestive disturbance, flatulence and vomiting; (*f*) presence of a tumor beneath the costal margin, right or left, at first movable with respiration, but soon becoming fixed; it can be carried into the costo-vertebral angle posteriorly, and can be pushed forward into the hollow of the palpating hand in front of the abdomen.

Bronzing of the skin is not usual unless both suprarenals are affected.

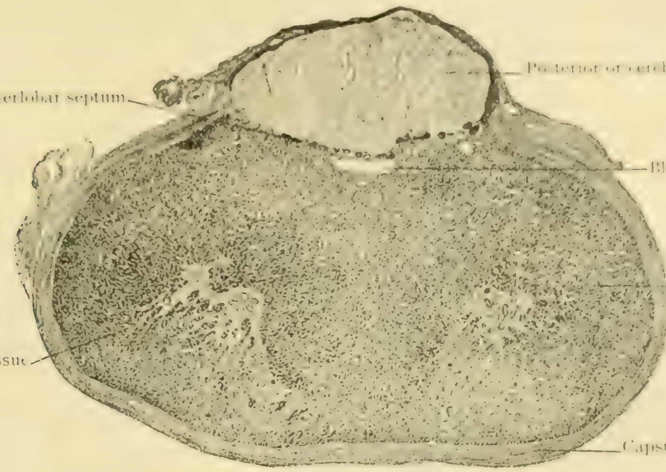
THE ANTERIOR LOBE OF THE PITUITARY BODY.

The pituitary body (**hypophysis**), although usually described in connection with the brain, to the base of which it is attached by a stalk continued from the infundibulum (Fig. 976), consists of two entirely distinct parts which differ both in their genesis and structure. These are the so-called anterior and posterior lobes. The latter, being derived from the diencephalon, is appropriately described with the brain (page 1130); the former, derived as an outgrowth from the roof of the primitive oral cavity, in view of its probable function as an organ of internal secretion, may be here considered, since in certain respects it resembles the thyroid body.

The anterior lobe, which constitutes the major part of the entire hypophysis, is kidney-shaped and receives the infundibular process in a hilum-like depression on its posterior surface. It increases in size until about the thirtieth year, when it measures in the transverse direction about 12 mm., in the sagittal about 7 mm., and in the vertical 5 mm. The anterior lobe of the hypophysis is light grayish red in color, the posterior appearing grayish white. It is surrounded by a well-marked fibrous capsule which forms, even where the two lobes are in contact, a distinct investment. In the anterior part of the lobe, on either side of the mid-line, a condensation of the connective tissue marks the position of large blood-vessels. Fine processes extend from the capsule inward and form a delicate net-work, rich in capil-

laries, the meshes of which are occupied by spherical or cord like masses of cuboidal or polygonal epithelial cells. The latter are principally of two kinds,—the smaller and slightly staining *chief cells*, from .003–.004 mm. in diameter, and the larger and

FIG. 1530.

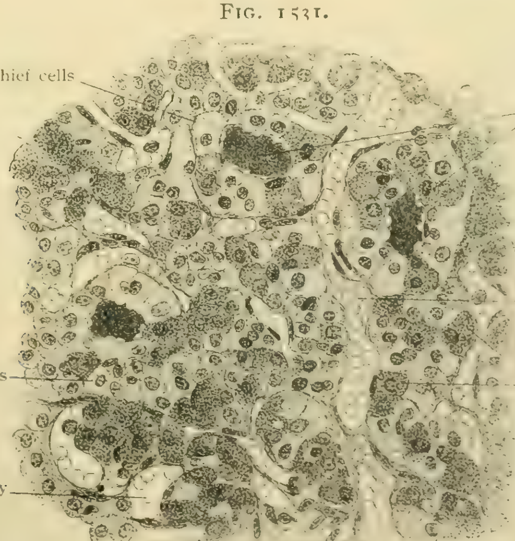


Transverse section of pituitary body, showing relation of anterior (oral) and posterior (cerebral) lobes. × 7.

deeply staining *chromophile cells* (.005–.008 mm.), so called because of their marked affinity for certain dyes. The two varieties of cells are arranged as intervascular anastomosing cords, in which, in a general way, the acidophilic cells occupy the periphery and the basophilic ones the centre. A third variety of cells, clear large elements, are found especially in the pars intermedia.

The aggregations of the cells, cord-like or spherical in form and usually without distinct lumen, lie in very close relation to the wide capillary blood-vessels that

FIG. 1531.



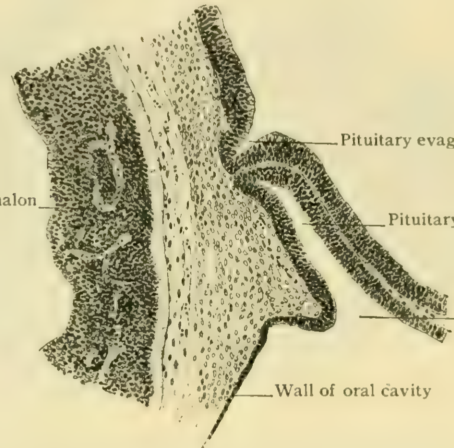
Section of anterior lobe of pituitary body; three acini contain colloid material. × 250.

ramify between them, supported by the delicate connective-tissue septa. Here and there, however, the glandular epithelium surrounds a lumen which may contain colloid material, thus resembling the acini of the thyroid body. The colloid-contain-

ing acini lie chiefly against the posterior lobe in what has been termed the *pars intermedia*. They are of moderate size and lined with cuboidal epithelium, and usually normally present, although colloid vesicles may be absent in other parts of the anterior lobe (Schoenemann).

The absence of excretory ducts, the activity of the epithelial cells as excretory elements, and their intimate relation to the blood-vessels all support the view that

FIG. 1532.

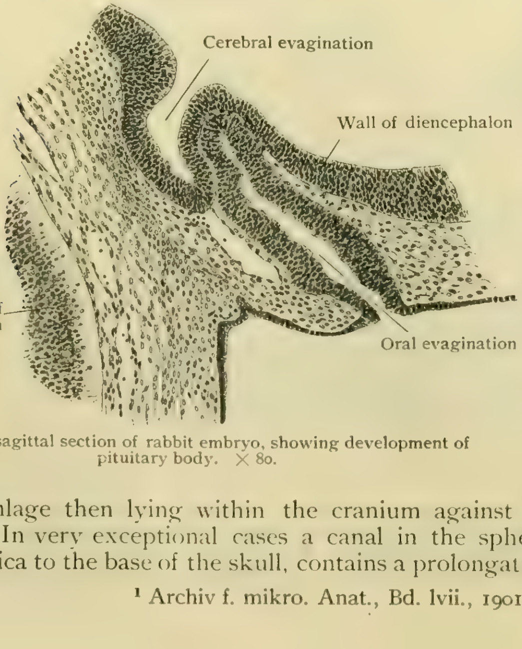


Portion of sagittal section of rabbit embryo, showing early stage of development of pituitary body. × 80.

the anterior pituitary lobe is to be regarded as an organ engaged in internal secretion. Its assumed function as directly concerned with somatic growth, suggested by the enlargement of the pituitary body observed in giants and in cases of acromegaly, needs further confirmation, since, as pointed out by Thom,[1] such changes are by no means constant.

Development.—As above stated, the two lobes of the pituitary body are developed from entirely different sources. While the posterior lobe originates as a tubular extension of the cavity of the interbrain (diencephalon), the anterior lobe is derived from an ectoblastic outgrowth from the primary oral cavity which appears during the fourth week. The cerebral end of this evagination (*Rathke's pouch*) soon expands into the hypophysial pouch, which remains connected with the mouth for a considerable time, until the formation of the base of the primitive skull leads to severance of the tubular communication, the hypophysial anlage then lying within the cranium against the lower surface of the interbrain. In very exceptional cases a canal in the sphenoid bone, leading from the sella turcica to the base of the skull, contains a prolongation of the hypophysis, and

FIG. 1533.

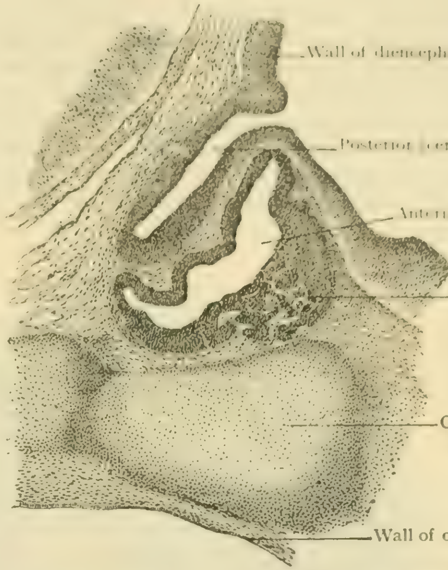


Portion of sagittal section of rabbit embryo, showing development of pituitary body. × 80.

[1] Archiv f. mikro. Anat., Bd. lvii., 1901.

thus represents the condition existing in some animals, in which the pituitary stalk persists during life, passing through a canal in the base of the skull and connecting with the oral epithelium. During the latter half of the second month the hypophysial sac sends tubular outgrowths into the surrounding vascular mesoblastic tissue. Later these tubules become separated from the main pouch, which latter often persists and becomes surrounded by acini to form the *pars intermedia*. The tubular outgrowths of other parts of the anterior lobe lose, in large part, their lumina and become solid cords separated by capillaries. The anterior lobe thus formed becomes pressed against the under surface of the brain-lobe with which it is closely bound.

FIG. 1534.



Portion of sagittal section of rabbit embryo, showing later stage of developing pituitary body. Anterior lobe now consists of numerous tubular acini. × 50.

The posterior pituitary lobe is developed from the tubular outgrowth from the diencephalon and retains its connection with the brain through the infundibulum. The primary lumen, however, becomes obliterated and the organ converted into a solid mass composed of tissue which resembles neuroglia and contains few or no cells that can be identified as nervous elements. Further details concerning the posterior lobe are given in connection with the brain (page 1130).

As a matter of convenience, mention may be made at this place of three organs —the *carotid bodies*, the *coccygeal body* and the temporary *aortic bodies*—concerning whose function little or nothing is known. The systematic position of these structures is at present uncertain, but from their histological characteristics the carotid and aortic bodies are probably to be regarded as closely related to or, in a sense, appendages of the system of sympathetic nerves, whilst the coccygeal body may be included, with seeming propriety, with the organs of internal secretion. Their grouping and description here, therefore, must be understood to be a matter of convenience and expediency and not an attempt to define their true relations.

THE CAROTID BODY.

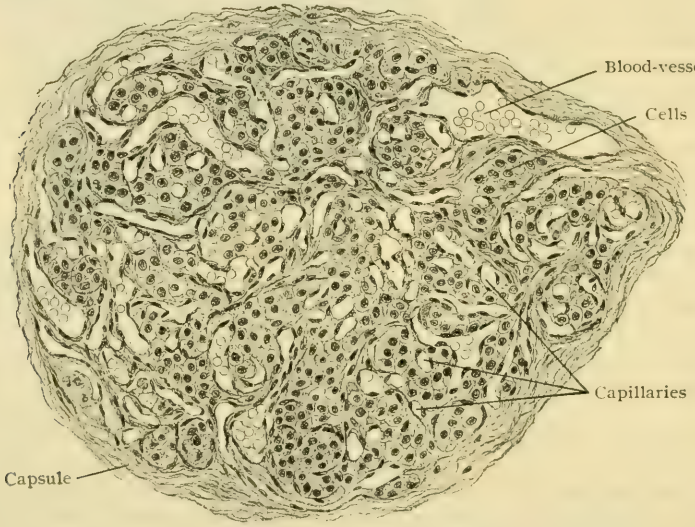
This organ (**glomus caroticum**), also known as the *carotid gland* and *ganglion intercaroticum*, is a small ovoid body measuring usually about 5 mm. in length, from 2.5–4 mm. in width and about 1.5 mm. in thickness. It may attain a length of 7 mm. and exists on both sides. Its most frequent position is on the median and deep side of the upper end of the common carotid artery in close relation with the point of division of the latter vessel into the external and internal carotids. The body usually lies not within the bifurcation, but rather on the inner side of the common carotid, so that its form and relations are best displayed by dissection from within outward. When freed from the surrounding fat and connective tissue, the carotid body appears of a grayish or brownish red, according to the condition of the capillary injection. The organ consists sometimes of two unequal divisions, united below.

Its **structure** includes a thin fibrous capsule, from which delicate septa penetrate inward and divide the organ into a small and uncertain number (5–15) of spherical masses or "lobules," from .2–.5 mm. in diameter, which consist of a com-

plex of blood-vessels, nerve-fibres and peculiar cells. The latter are irregularly disposed as clumps or cell-balls (Schaper[1]) and occupy the interspaces within the close net-work of large capillaries which ramify among the cells. The characteristic elements of the carotid body are the polygonal cells, about .01 mm. in diameter, with large round nuclei. Their protoplasm is finely granular and is especially prone to change, being best preserved in solutions of chromic acid salts. When so treated, they take on the peculiar yellow color entitling them to be classed as *chromaffine cells*. The large number of nerve-fibres within the carotid body is remarkable. They are mostly nonmedullated and are derived chiefly from the neighboring sympathetic plexus surrounding the carotid artery and, after entering at different places, ramify within the organ in all directions, the finest filaments being lost among the groups of cells. The penetrating nerve-trunks usually enclose typical ganglion-cells and, in a sense, the chromaffine cells likewise, since the nerve-fibres surround the groups of these elements.

FIG. 1535.

Carotid Body



Section of adult human carotid body; one entire lobule is shown. × 170.

In view of (1) the identity of its elements with other chromaffine cells, which are now recognized as closely associated with the sympathetic system in other localities, as in the medulla of the suprarenal body, (2) its extraordinary richness in nerve-fibres, (3) its general resemblance to a sympathetic ganglion, and (4) its direct development from embryonal sympathetic ganglion cells, Kohn[2] concludes that since the carotid body is neither a gland nor a typical ganglion it must be regarded as accessory to the sympathetic system and, in recognition of this relation, proposes the name *paraganglion caroticum* for the organ. Concerning its function nothing is definitely known.

The blood-vessels supplying the carotid body are branches which pass directly from either the common carotid artery or its terminal branches.

THE COCCYGEAL BODY.

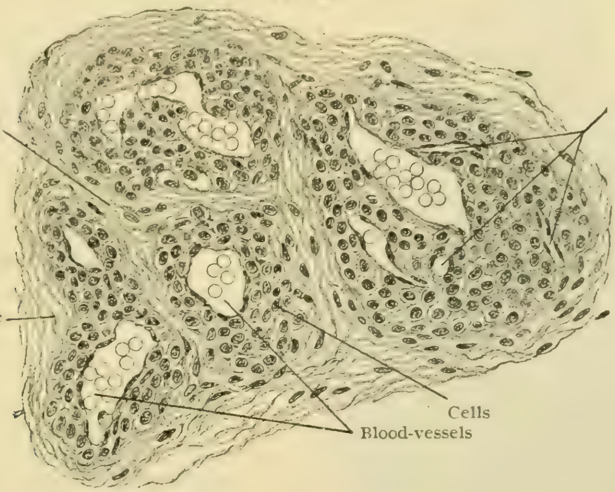
This organ (**glomus coccygeum**), also often called the *coccygeal gland*, or *Luschka's gland* (in honor of the anatomist who described it half a century ago[3]), is a small reddish yellow ovoid body which lies embedded in fatty areolar tissue usually immediately in front of the tip of the coccyx, but sometimes just below. According to Walker,[4] the surest guide to the body is the middle sacral artery, to whose ante-

[1] Archiv f. mikros. Anatomie, Bd. 40, 1892.
[2] Archiv f. mikros. Anatomie, Bd. 56, 1900.
[3] Die Hirnanhang und die Steissdrüse des Menschen. Berlin, 1860.
[4] Archiv f. mikros. Anatomie, Bd. 64, 1904.

rior surface the little organ is attached, its long axis lying transverse to that of the blood-vessel. Approached from the posterior surface, the body is found just beneath or within a small opening in the tendinous insertion of the levator ani muscle into the last coccygeal segment, covered by the origin of the external sphincter muscle (Luschka). The dimensions of the organ are small, its transverse and greatest diameter being from 2.5–3 mm. and its thickness less than 2 mm. It sometimes is divided into two or even more tiny lobes. The body thus described is, however, only the largest of a series of nodules which includes a variable number of structures, for the most part of minute size, irregularly grouped around the chief mass (Walker). The additional nodules are in many cases connected with the principal body by means of delicate pedicles, in others entirely free, but in all instances they are grouped around the middle sacral artery or its branches. In opposition to the prevailing belief, Walker found neither an unusually rich nerve-supply nor intimate connection between the coccygeal body and the sympathetic.

FIG. 1536.

Coccygeal gland



Section of human adult coccygeal body. × 220.

The **structure** of the body, as seen in transverse sections (Fig. 1536), includes an irregularly oval field of connective tissue, fairly well defined from the surrounding fatty areolar tissue, in which are enclosed numerous aggregations of epithelial cells and, sometimes, a thick-walled artery. The proportion of cell-masses to the connective tissue stroma varies, in some cases the cellular constituents predominating, but commonly the fibrous stroma being the more bulky. The individual cell-groups are uncertainly circumscribed by a slight condensation of the surrounding fibrous stroma. Each aggregation of cells contains a central blood-space, limited by an endothelial wall similar to that of a capillary. Against this wall the epithelial cells lie without the intervention of connective tissue; likewise the cells themselves are closely packed in direct apposition with one another and in consequence present a polygonal contour. They are disposed around the central vessel in from two to five layers, the individual cells being indistinctly outlined and composed of clear protoplasm containing a relatively large and deeply staining nucleus. Concerning the mooted question as to the presence of chromaffine cells within the coccygeal body, the testimony of Walker, Schumacher and especially of Stoerk[1] as to their absence seems convincing. The last-named investigator concludes that these cells at no period exhibit the chrome-reaction, and, further and in opposition to Jakobsson, that they have no histogenetic relation to the sympathetic system. On the other hand, the epithelial character of the cells, their intimate relation to the blood-vessels, and the absence of

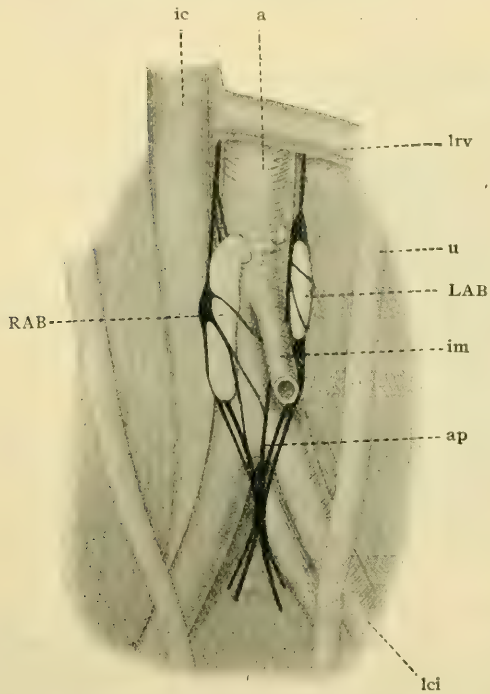
[1] Archiv f. mikros. Anatomie, Bd. 69, 1906.

excretory ducts, seem to justify the inclusion of the coccygeal body, at least, provisionally, among the organs of internal secretion, as suggested by Walker.

THE AORTIC BODIES.

These temporary organs were described by Zuckerkandl[1] a few years ago and are also known as the *bodies of Zuckerkandl.* According to their discoverer, as found in the new-born child, they are a pair of small narrow bodies that lie upon the anterior surface of the abdominal aorta, opposite the origin of the inferior mesenteric artery (Fig. 1537), in close relation with the aortic plexus of the sympathetic nerves. Although usually separated, in about 15 per cent. of the bodies examined, in which they were invariably present, the bodies were joined by an isthmus into a horseshoe-shaped organ of varying dimensions. The right body is usually the larger, with an average vertical length of 11.6 mm. the corresponding dimension of the left body being 8.8 mm. The extremes of length for the right body are from 8–20 mm., and of the left one from 3–15 mm. The width is about one-fifth of the length, and the thickness something less. The surface of the little organ is smooth and its color light brown. Whilst its consistency is about the same as that of the neighboring lymph-nodes, the body is softer than the adjacent sympathetic ganglia. The aortic bodies are essentially organs of fœtal life or at most of early childhood, and in the adult they are represented by mere atrophic remains (Zuckerkandl).

FIG. 1537.



Aortic bodies of new-born child; *RAB, LAB*, right and left aortic bodies; *a*, aorta; *im*, inferior mesenteric artery; *lci*, left common iliac; *ic*, inferior cava; *lrv*, left renal vein; *ap*, aortic sympathetic plexus; *u*, ureter. × 2. (*Zuckerkandl.*)

The **structure** of the aortic body includes a fibrous capsule, which is prolonged into the interior as connective tissue strands that accompany the numerous blood-vessels entering the organ. The arteries, minute twigs from the aorta, the inferior mesenteric and sometimes the spermatic, break up into a rich capillary net-work whose wide meshes are filled with closely packed cells of varying size. These are polygonal, spherical or cuboidal in form and distinguished in many cases by exhibiting the peculiar color reaction, after treatment with the chrome-salts, entitling them to be classed as chromaffine cells. According to the observations of Zuckerkandl, the genetic relations of the sympathetic ganglia, the medulla of the suprarenals, and the aortic bodies are most intimate, since these various structures are derivatives of a continuous primary cell-mass. In consideration of this association and the constant presence of the distinctive chromaffine cells, it is highly probable that the aortic bodies are to be regarded, along with the medullary portion of the suprarenal and the carotid bodies, as appendages or paraganglia of the sympathetic.

[1] Verhandlungen der Anatom. Gesellschaft, 1901.

THE ORGANS OF RESPIRATION.

This tract includes the organs by which an interchange of gases takes place between the blood and the air. It consists of the *larynx*, the *trachea* or windpipe, and its subdivisions, the *bronchi*, the *lungs*, and the serous membranes, the *pleuræ*, which surround them. Morphologically this tract is an outgrowth from the fore-gut. The larynx is a specialized apparatus for the production of the voice, situated at the beginning of the windpipe, of sufficient importance to be considered by itself.

THE LARYNX.

The larynx consists of a number of cartilages which, by their relative changes of position, modify the approximation and tension of two folds of mucous membrane over fibrous tissue, known as the vocal cords, on either side of the cleft through which the air enters the windpipe. The larynx is in the neck, being suspended from the hyoid bone and leading to the trachea. It is practically subcutaneous in front. Its superior orifice is behind the base of the tongue, and can be seen in life only by a mirror. The cartilages are connected by joints and ligaments, moved by muscles, and covered by mucous membrane, the folds of which form important morphological parts of the larynx.

THE CARTILAGES, JOINTS, AND LIGAMENTS.

The cartilages which form the framework of the larynx are three single ones : the *cricoid*, the *thyroid*, and the *epiglottis;* and three pairs: the *arytenoid cartilages*, the *cornicula laryngis* or *cartilages of Santorini*, and the *cuneiform cartilages* or those of *Wrisberg*. The last pair, although determining well-defined swellings of the mucous membrane, are very small ; indeed, the cartilage is not always to be found. There are other minute points of cartilage to be mentioned with the structures in which they occur.

The epiglottis, the upper part of the cartilages of Santorini, those of Wrisberg, and the ends of the vocal and apical processes of the arytenoids consist of elastic cartilage, the others being of hyaline cartilage. The cricoid and arytenoid cartilages are derivations from the trachea and represent the more primitive form of larynx. The thyroid and the epiglottis appear in mammals. In monotremes the epiglottis is of hyaline cartilage.

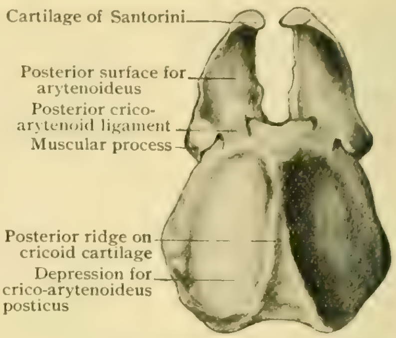
The Cricoid Cartilage.—This is the foundation of the larynx, being a ring on the top of the trachea. It is nearly circular, the diameter in the male being 19 mm. (Luschka). It is narrow in front, being from 3–8 mm., usually about 5 mm. broad, and some four or five times as much behind. The height at the back is approximately 25 mm. in the male and from 16–23 mm. in the female. The cricoid is 3 or 4 mm. thick in the lower part and in the upper as much as 5 or 6 mm. The posterior aspect is somewhat quadrilateral, the upper border descending very steeply at the sides. Internally the cricoid is perfectly smooth. The lower border presents a slight median descent in front and an inconspicuous notch behind. Nevertheless, the cricoid is so placed that its posterior margin is a trifle the lower. A small median depression occurs in the superior border behind, and on either side is an *articular eminence* for the arytenoid cartilage. Being situated on the superior border of the cricoid, this elongated eminence has its long diameter (8–10 mm.) slanting outward, downward, and somewhat forward. Its free edge may be slightly convex or concave in the long axis, but is not far from straight. It is convex transversely and about 4 mm. thick. The whole elevation is inclined slightly away from the interior of the larynx, so as somewhat to overhang its posterior surface, and is

Fig. 1538.

Cricoid cartilage, right lateral aspect.

extremely variable in all its details. A median ridge divides the *posterior surface* of the cricoid cartilage into two symmetrical depressions for the origin of the posterior crico-arytenoid muscles. Each *lateral surface* of the cricoid, below the middle, and nearer the back than the front, bears an oval *articular facet* for the crico-thyroid joint, its long diameter extending upward, backward, and inward. The facet, which is nearly plane, faces chiefly outward, but also somewhat upward and a little backward. The long diameter is about 5 mm. and the cross one nearly as great. A ridge connecting it with the superior articular facet bounds the posterior surface of the cartilage. The *anterior surface* of the cricoid is somewhat convex vertically, so as to resemble an over-large tracheal ring.

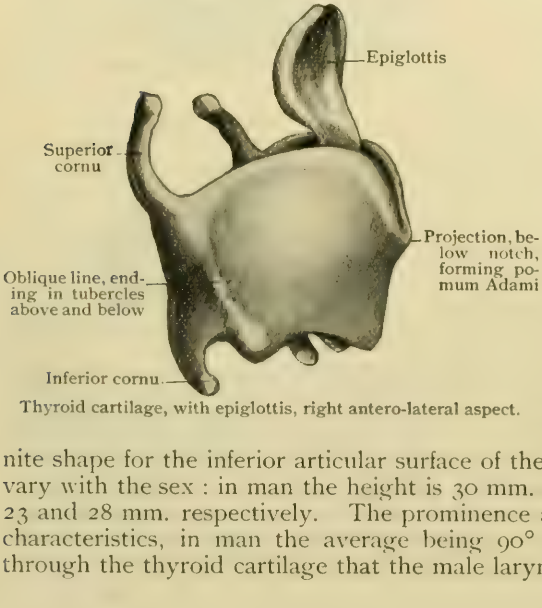
FIG. 1539.



Cricoid and arytenoid cartilages from behind.

The Thyroid Cartilage. — This, the shield-shaped cartilage, consists of two quadrilateral plates, the *alæ*, broader than high, which meet in front and are widely apart behind. The posterior border of each is prolonged upward and downward into two horns, or *cornua*, somewhat flattened from side to side. The lower pair rest on the inferior articular facets of the cricoid and the upper are attached by ligaments to the ends of the greater horns of the hyoid bone. Being thus open behind, the thyroid cartilage is complementary to the cricoid upon which it rests. The *thyroid notch* (**incisura thyroidea**) is a deep median depression of the upper border in front, extending nearly or quite half-way down. The plates are strongly everted (especially in the male) at the sides of the notch, thus causing most of the prominence known as Adam's apple (**protuberantia laryngea**). The resulting median ridge ends shortly below the notch, and at the lower border the front of the thyroid is smooth and convex. The upper border is slightly convex on either side, and usually presents a small notch just in front of the root of each superior horn. The *superior tubercle* is a little prominence on the outer surface, just below and anterior to this notch. The lower border is alternately convex and concave. There is a moderate median convexity followed by a hollow, external to which is a marked prominence, the *inferior tubercle*, between which and the inferior horn is a deep notch. The posterior border is slightly concave in the middle. The *oblique line* is a ridge running downward and forward from the upper tubercle to the lower. It marks the interruption of the muscular layer out of which the sterno-thyroid and the thyro-hyoid muscles arise. The inferior constrictor of the pharynx is inserted behind it. The *superior horns*, usually longer and more flexible than the inferior, run upward, backward, and inward. They become more cylindrical and have blunt rounded ends. The *inferior horns*, broader than thick, run downward and slightly inward, with a turn forward at the ends. Internally each presents near the tip a round articular surface of indefinite shape for the inferior articular surface of the cricoid. The dimensions of the alæ vary with the sex: in man the height is 30 mm. and the breadth 38 mm.; in woman, 23 and 28 mm. respectively. The prominence and sharpness of the angle are male characteristics, in man the average being 90° and in woman 120°. It is chiefly through the thyroid cartilage that the male larynx acquires its relatively large size.

FIG. 1540.



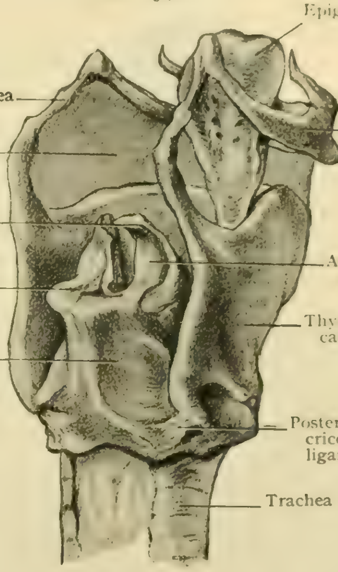
Thyroid cartilage, with epiglottis, right antero-lateral aspect.

Development and Growth.—The thyroid, probably formed from the fourth and fifth branchial arches, is originally rounded in front, the angle becoming prominent at puberty, when the great increase in size in the male and the greater prominence occur. A slight strip of cartilage, separate from the rest, is found in the angle in early childhood ; subsequently it becomes less and less distinct.

Variations.—It is not rare to find a foramen near the upper outer angle, a little below the superior tubercle, which transmits the superior laryngeal artery and exceptionally some fibres of the external branch of the superior laryngeal nerve. Assuming that the thyroid is developed as above stated, the foramen represents a cleft between the fourth and fifth branchial bars. It is common for one of the superior horns to be shorter than the other, and not very rare for one to be absent. Our experience agrees with that of others in finding the absence more common on the left side.

Joints and Ligaments connecting the Thyroid with the Cricoid Cartilage and with the Hyoid Bone.—The **crico-thyroid joints**, between the lower articular facets of the cricoid and the inferior horns of the thyroid, are very indefinitely shaped. The facet of the thyroid is on the inner side of the inferior horn, and is nearly plane, but either participant of the joint may be the contained one. The capsule is lax, although somewhat strengthened by two by no means constant ligamentous bands. An anterior one extends downward and forward from the front of the lower horn ; a posterior one extends upward and backward from the back of the same. The motion is usually described as rotation on a transverse axis passing through both joints, but in fact a great deal of irregular sliding is possible.

Fig. 1541.



Cartilages of larynx united by their ligaments ; right half of thyrohyoid membrane has been removed ; postero-lateral aspect.

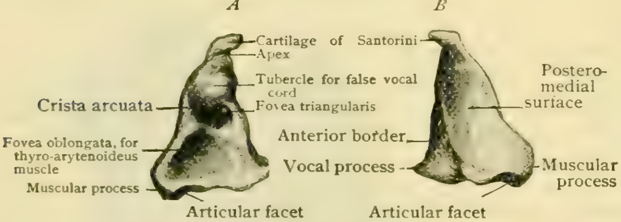
The **crico-thyroid membrane,** although connecting the cartilages in front, has no direct attachment to the thyroid at the sides, and consists of a central anterior and a lateral part. The *anterior part*, also known as the *conoid ligament*, is triangular in shape, with its base attached to the upper edge of the cricoid cartilage and its truncated apex to the lower border of the thyroid. This is the strongest part of the membrane, containing considerable elastic tissue, and closes the middle of the space between the two cartilages. It is pierced by several small holes for blood-vessels, and is crossed superficially by the crico-thyroid artery. The *lateral part* (Fig. 1544), while directly continuous with the anterior and attached below to the upper border of the anterior arch of the cricoid cartilage, is thin and membranous, and on each side extends upward and inward beneath the lower border of the thyroid ala without being attached. The upper border of this part of the membrane becomes directly blended and continuous with the inferior thyro-arytenoid ligament, the latter being practically the thickened and free superior border of the crico-thyroid membrane, which in this sense becomes the supporting framework for the true vocal cord. The lateral crico-arytenoid and thyro-arytenoid muscles intervene between the thyroid ala and the lateral part of the membrane. The inner surface of the latter is covered by the laryngeal mucous membrane.

The **thyro-hyoid ligament** or **membrane** is one continuous sheet of fibrous tissue, the posterior borders of which are thickened as they extend between the supe-

rior horns of the thyroid and the tips of the greater horns of the hyoid. They may be artificially dissected to resemble cords (ligamenta thyreohyoidea lateralia), although in fact they are continuous, not only with the rest of the membrane, but with its expansion which mingles with the fasciæ of the neck. As a rule, a little nodule (*cartilago triticea*) is found in the middle of this lateral thickening (Fig. 1541). According to Gegenbaur, it is the remnant of a closer connection between the third and fourth branchial bars. The more membranous part of the ligament extends from the superior border and the inner side of the superior horns of the thyroid to the upper border of the body of the hyoid and its greater horn. A *bursa*, extending under the body of the hyoid, lies on the anterior surface of this membrane, which is denser beneath it.

The Arytenoid Cartilages.—These are a pair of very irregular four-sided pyramids (one side being the base) perched on the superior articular facets of the cricoid. The vocal cords extend between them and the entering angle of the thyroid. Besides the *base*, there is a *posterior*, an *internal*, and an *antero-external surface*, separated by tolerably distinct borders. A section near the base is semilunar, the boundary between the posterior and internal surfaces being effaced. The two remaining angles are each prolonged (Fig. 1542). The anterior, extending forward as the *vocal process* for the attachment of the true vocal cord, is long and slender; the external or *muscular process*, short and thick, projects outward and backward. The base is chiefly occupied by an oval articular cavity resting on that of the cricoid. The long axis of this articular facet, which does not much surpass its transverse one, extends in the main forward, crossing that of the opposed facet. The concavity is nearly at right angles to the long axis. The posterior surface is well defined and deeply concave, being filled by the arytenoid muscle. The internal surface is nearly plane, offering nothing for description. The antero-external surface is triangular. A ridge, the *crista arcuata*, starts from the vocal process and runs backward and upward, ultimately describing nearly a circle around a hollow, the *fovea triangularis*, which is quite as often oval. This little hollow is filled by a mass of glands, and is overlooked unless the cartilage be cleaned very carefully. The false vocal cord is attached to a little tubercle on this ridge either above or behind the fovea. The borders meet above at a blunt apex.

FIG. 1542.



Right arytenoid cartilage, capped by cartilage of Santorini. *A*, antero-lateral aspect; *B*, postero-medial aspect. × $\frac{3}{2}$.

The Crico-Arytenoid Joint.—From the foregoing description of the two opposed articular surfaces it is evident that in consequence of the crossing of their long axes the whole of one is not in contact with the whole of the other. The joint is surrounded by a lax *capsule*, strengthened behind by straight vertical fibres, which have been called the *posterior crico-arytenoid ligament* (Fig. 1541). The motions are very difficult to analyze. The arytenoid may tip on the elongated elevation of the cricoid or slide along it; moreover, it may rotate upon it at any point occupied. This movement, from the nature of the surfaces, is a screw motion rather than a true rotation, but the term is sufficiently accurate.

The Epiglottis.—This is a leaf-shaped plate of elastic cartilage which, inserted by its stalk into the angle of the thyroid, rises above the hyoid bone and guards the entrance into the larynx. The length is some 3.5 cm. The epiglottis expands transversely and curls forward over the root of the tongue. Its posterior surface is entirely free, but less than the upper half of the anterior surface is exposed. Beginning at the free border, which is bent forward towards the tongue, the posterior surface is convex, slightly concave, and finally convex again, owing to a prominence, called the *tubercle*, which its root forms in the larynx. The free edge is rounded transversely and the posterior surface in the main concave across. The stalk, when well developed, is triangular on section, fitting into the angle of the thyroid. The

cartilaginous stroma is full of pits, or even perforations, containing glands. The mucous membrane is attached to it very closely, so that in dissecting the cartilage it is difficult to determine its true outline.

The Ligaments of the Epiglottis.—The *thyro-epiglottic ligament* is an elastic band continuing the stalk of the epiglottis into the angle of the thyroid, just below the notch. Owing to the ill-defined structure of the epiglottis, it is often hard to say what is ligament and what is stalk. The *glosso-epiglottic ligaments*, one median and two lateral, are three folds of mucous membrane with more or less elastic tissue within them, extending from the front of the epiglottis to the tongue, with which they have been more particularly described (page 1575). The *hyo-epiglottic ligament*[1] is described as a bundle of elastic tissue extending between the middle of the anterior surface of the epiglottis and the upper border of the hyoid. Such a structure may be artificially dissected; but the important point is the presence of a mass of very dense areolar tissue, probably largely elastic, and with fat in its meshes, which forms a firm pad between the front of the epiglottis below the line of reflection of the mucous membrane and the thyro-hyoid membrane which is attached to the upper border of the hyoid. This mass gives support to the epiglottis, and probably may be made to press it backward when the hyoid is carried in that direction. It is continuous with the septum of the tongue.

FIG. 1543.

Epiglottic cartilage from behind.

The Movements of the Epiglottis.—The old idea that the epiglottis turns over backward like a lid to close the larynx in swallowing is disproved. That it could ever be so bent is unlikely. In swallowing it is carried bodily backward, while the approximated aryepiglottic folds and tubercles of Santorini are drawn upward, thereby closing the laryngeal aperture. While there are muscular fibres in the aryepiglottic fold, they are scanty and irregular and hardly capable of exercising any great influence on the shape of the epiglottis.

The **cornicula laryngis,** or *cartilages of Santorini*, are a pair of small horn-like structures of elastic cartilage on the apices of the arytenoids (Fig. 1542). As their sheath is continuous with the perichondrium of the latter, they are not very easily isolated. They are 4 or 5 mm. long, curve backward and inward, and are attached by their fibres to the arytenoids.

The **cuneiform cartilages** (*of Wrisberg*) are two very slender rods of elastic cartilage situated a little in front of the corniculæ laryngis in the aryepiglottic folds (Fig. 1545). They are some 5 mm. or more long and 1 mm. thick. While the swellings which they seem to produce in the folds are constant, the same cannot be said of the cartilages. They are often difficult to isolate.

Minute nodules of elastic cartilage are occasionally found in certain parts of the larynx. The *posterior sesamoid cartilages* are on the lateral sides of the joints between the arytenoids and the corniculæ. The *anterior sesamoid*, which may be double, is at the anterior origin of the true vocal cords. An occasional *interarytenoid* has been described under the mucous membrane of the pharynx between those cartilages. It is regarded as representing a *precricoid* cartilage.

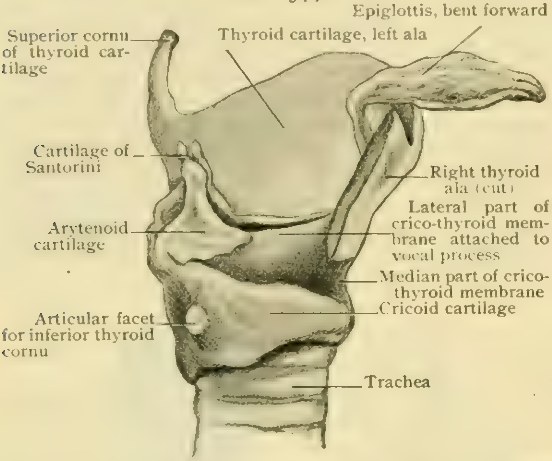
The **elastic sheath of the larynx** is a layer of areolar tissue, rich in elastic fibres, which lines the inside of the larynx, and is prolonged from it into the folds of mucous membrane to be presently described. The superior and inferior thyro-arytenoid ligaments in the false and true vocal cords respectively are thickenings of this layer.

The **superior thyro-arytenoid ligaments** (ligamenta ventricularia), one on each side, extend between the angle of the thyroid above its middle (the point of origin will be described accurately with the vocal cords) and the tubercle on the border of the fovea of the arytenoid. They are in no sense ligaments, but at most slight thickenings of the elastic tissue in the folds of the mucous membrane forming the false vocal cords, and can be demonstrated only by an artificial dissection.

[1] Dieulafé : La membrane glosso-hyoidienne, Bibliographie Anatomique, tome xi., 1901.

The **inferior thyro-arytenoid ligaments** (**ligamenta vocalia**) are a pair of bands of fibrous tissue, chiefly elastic, supporting the free edges of the true vocal cords, extending from the angle of the thyroid a little below the false ones to the vocal processes of the arytenoids. These ligaments are continuous with the lateral parts of the crico-thyroid membrane, as the thickened and modified upper borders of which they may be regarded (Fig. 1544). Each band is triangular on section, having the free edge at that of the cord. There may be a minute nodule of cartilage in the ligament just in front of its posterior attachment.

FIG. 1544.



Lateral view of larynx after removal of greater part of right thyroid ala, showing attachment of crico-thyroid membrane to arytenoid cartilage. The free border of the membrane constitutes the thyro-arytenoid ligament and the framework of the vocal cord.

Ossification of the Larynx.—The process, beginning as it does at about twenty, is a normal change. Chievitz[1] found some ossification in every male larynx of over twenty and in every female one of over twenty-two. It appears at about the same time in the cricoid and thyroid,—namely, at about the beginning of the twentieth year,—and in the arytenoid at about the middle of the twenties in man and nearer the thirties in woman.

The Cricoid.—The first nucleus appears on each side at the back of the facet for the arytenoid, and almost at the same time another appears at its front. These are shortly followed by one at the joint for the thyroid. These three unite, forming a lateral ossification which spreads across the back. One or more points appear in front near the upper border of the arch, which is thus ossified and joins with the sides. After these various unions the entire lower border of the cricoid is still cartilaginous. The youngest man observed by Chievitz with complete ossification was forty-four and the youngest woman seventy-six.

The Thyroid.—The process begins near the posterior inferior angle and invades the inferior horn. It appears next near the lower part of the anterior angle, and these two centres on each side join by spreading along the inferior border. The superior horn then ossifies either by a separate centre or by extension along the hind border. Finally a tongue-like process, starting near the inferior tubercle, extends upward and forward across the ala to meet the ossification which has spread along the superior border, leaving before and behind it places which are the last to ossify. This tongue-like process is peculiar to the male; in the female ossification advances chiefly from the posterior border. The youngest man with complete ossification of the thyroid was fifty and the youngest woman seventy-six.

The Arytenoids.—The process begins in the base. In man the starting-point is the muscular process, but in woman it is less certain. The youngest man in whom the process was complete was seventy-five and the youngest woman eighty-five.

The *cartilago triticea*, when present, also tends to ossify.

THE FORM OF THE LARYNX AND ITS MUCOUS MEMBRANE.

The shape of the larynx depends not only on the cartilages, but also on folds of mucous membrane stretched over bands of connective tissue and over muscles.

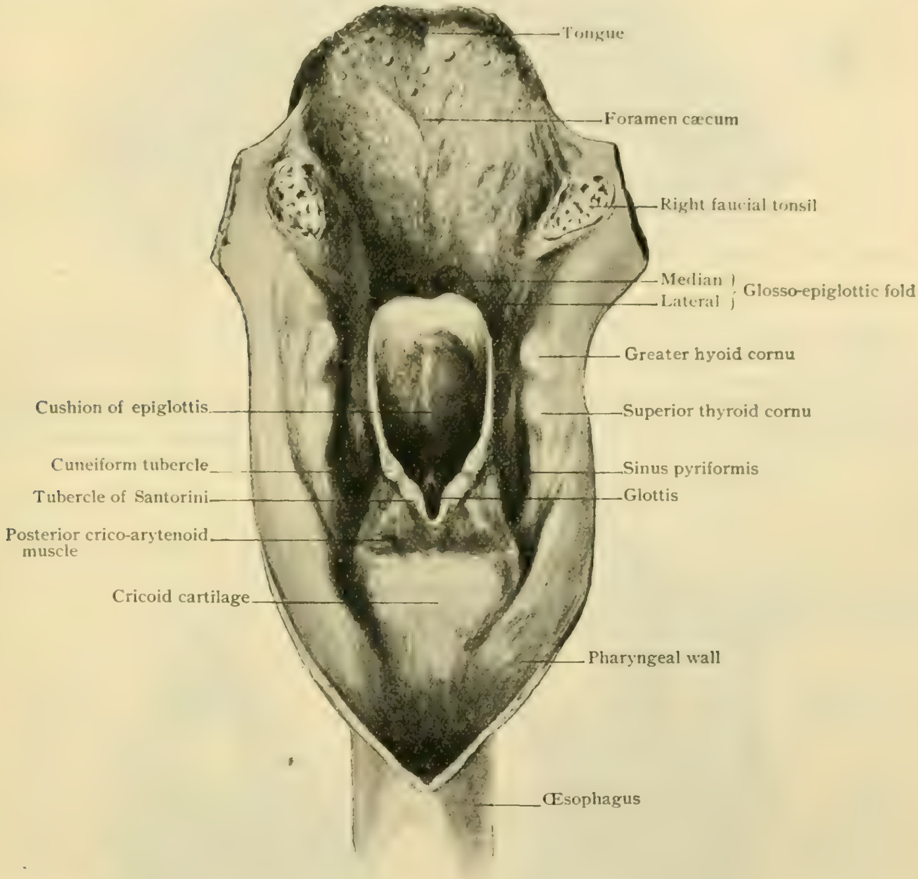
The cavity of the larynx is subdivided into three parts: the *supraglottic*, the *glottic*, and the *infraglottic*.

The **supraglottic region** (**vestibulum laryngis**) begins with the entrance to the larynx, an oval (or rather a heart-shaped) plane, which, owing to the height and the position of the larynx, faces nearly backward. It is bounded by the free border of the epiglottis in front and by the *aryepiglottic fold* which passes from this on either side back over the top of the arytenoid cartilages. It is interrupted in the median line behind by a notch. On either side of this the fold presents a small swelling (**tuberculum corniculatum**), caused by the cartilage of Santorini, anterior to which is a larger one (**tuberculum cuneiforme**) containing that of Wrisberg. Between

[1] Archiv f. Anat. und Phys., Anat. Abth., 1882.

these and the sides of the epiglottis the fold contains only the general fibrous envelope and some stray muscular fibres. Below the entrance in front lies the posterior surface of the epiglottis, concave from side to side, and presenting in the median line, from above downward, first a convexity, extending so far back as to overhang much of the larynx, then a hollow, and finally a prominence, the *tubercle* or *cushion*. A deep crease descends on each side, bounding the lower part of the epiglottis, and meeting its fellow below the tubercle. The mucous membrane is very closely attached to the epiglottis, and so thin that the straw color of the cartilage is seen through it, turning into red at the lower part. The pits for the glands in its substance can also be made out. The lateral wall of this region, which is separated from the front by

FIG. 1545.



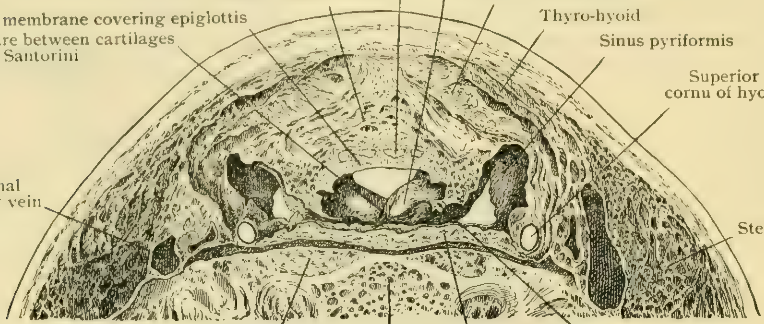
Pharynx opened from behind, showing superior laryngeal aperture and mucous pouches embraced by wings of thyroid cartilage; cricoid cartilage and muscles are covered with mucous membrane.

the crease, inclines inward, and becomes the fold of mucous membrane known as the false vocal cord. Farther back a shallow groove, the *philtrum*, runs from the interval between the tubercles of Santorini and of Wrisberg to the ventricle.

The *sinus pyriformis* (Figs. 1545, 1354) is a shallow cavity to the outer side of the aryepiglottic fold, bounded externally by the greater horn of the hyoid, the upper part of the ala of the thyroid, and the thyro-hyoid membrane between them. It is bilateral and properly a part of the pharynx (page 1598). Its mucous membrane, continuous with that of the larynx, is smooth and thin, and but loosely attached to the areolar tissue below it. In the front part there is a transverse fold caused by the internal branch of the superior laryngeal nerve passing from the thyro-hyoid membrane, which it perforates, to the larynx proper.

The **glottic region** extends from the free edges of the false cords above to those of the true ones below. The narrowest part of the larynx, the *rima glottidis* or *chink of the larynx*, is the interval between the true cords in front and the arytenoid

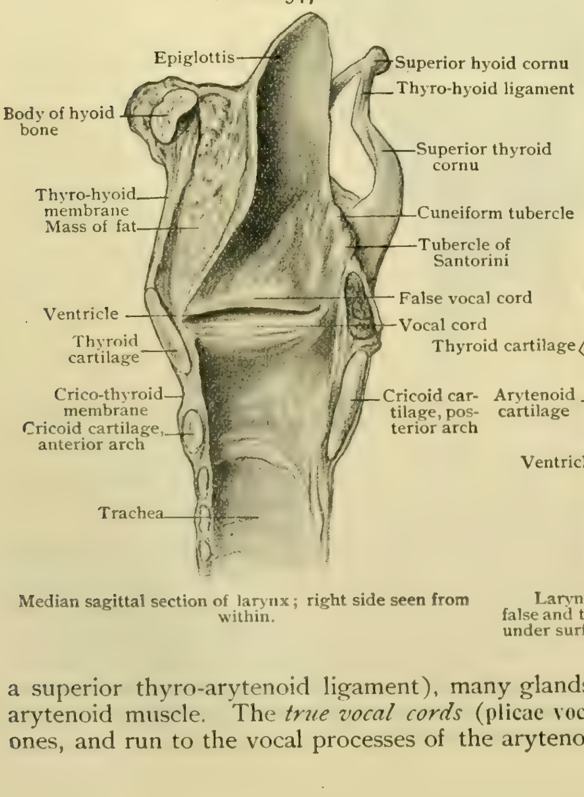
FIG. 1546.



Anterior part of section across neck at level of fourth cervical vertebra, passing through upper part of superior aperture of larynx.

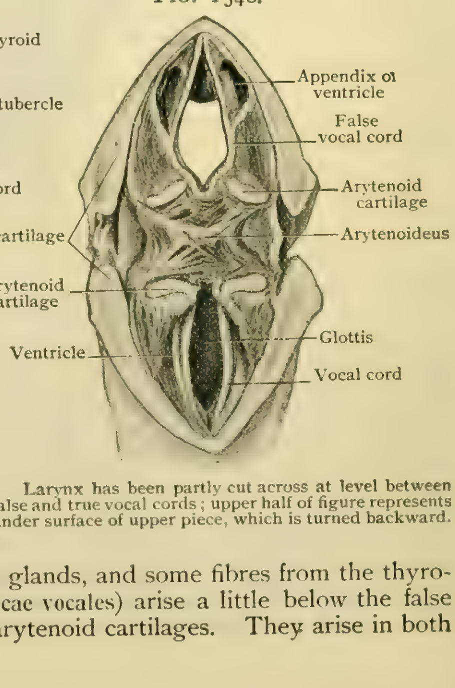
cartilages behind. The *false vocal cords* (plicae ventriculares) are folds of mucous membrane continuous with the sides of the supraglottic space. They are attached in front to the inner side of the angle of the thyroid, above its middle, and behind to the antero-external surface of the arytenoids. They are soft folds of mucous membrane containing connective tissue (out of which a skilful dissector can manufacture

FIG. 1547.



Median sagittal section of larynx; right side seen from within.

FIG. 1548.

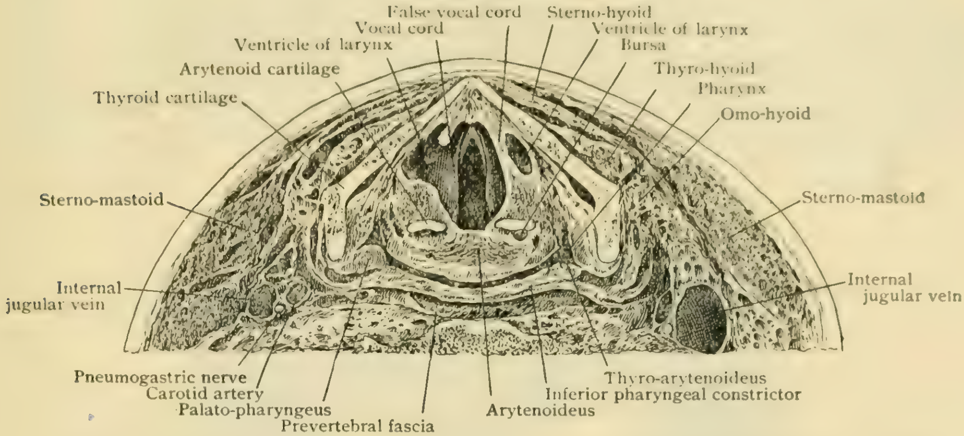


Larynx has been partly cut across at level between false and true vocal cords; upper half of figure represents under surface of upper piece, which is turned backward.

a superior thyro-arytenoid ligament), many glands, and some fibres from the thyro-arytenoid muscle. The *true vocal cords* (plicae vocales) arise a little below the false ones, and run to the vocal processes of the arytenoid cartilages. They arise in both

sexes a little above the middle of a line from the bottom of the thyroid notch to the lower border of the thyroid. Taguchi[1] gives the average distance in men from the notch to the vocal cord as 8.5 mm., and from below as 10.5 mm. In women he finds these distances 6.5 mm. and 8 mm. respectively. The cords arise either directly from the thyroid, just on each side of the depth of the angle, or from a

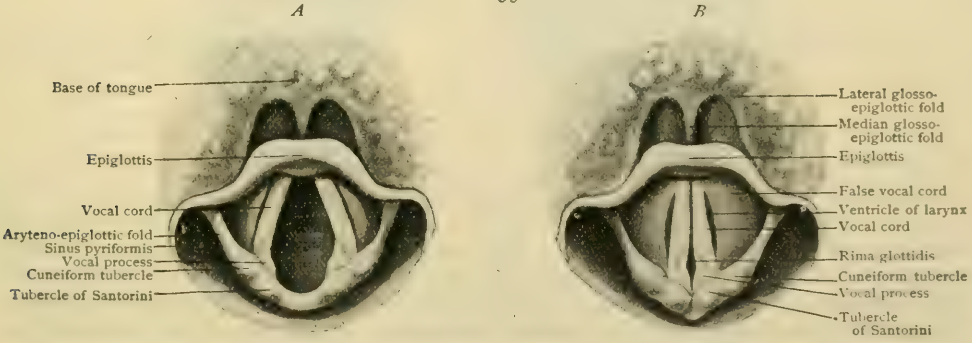
FIG. 1549.



Anterior part of section across neck at level of false vocal cords; on left side ventricle of larynx is exposed.

median cartilaginous nodule, or from one for each cord, the distance between them being 1.5 mm. in both sexes. The false cords arise about 3.5 mm. above the true ones, and, on the average, 4 mm. apart from each other. The true cords are triangular on section, with a sharp free edge, an upper surface slanting downward and outward from it, a longer internal surface which slants steeply downward and outward, and an imaginary attached base placed laterally. The free edge is composed of the whitish ligament which shows through the thin and closely attached mucous membrane. The substance is chiefly muscular tissue from the thyro-arytenoid, which forms a three-sided prism, giving a solidity which the false cord lacks. Behind the cords the glottic-region is bounded by the arytenoid cartilages, and, as the true

FIG. 1550.



Interior of larynx as seen with laryngoscope. *A*, rima glottidis widely open; *B*, rima glottidis closed.

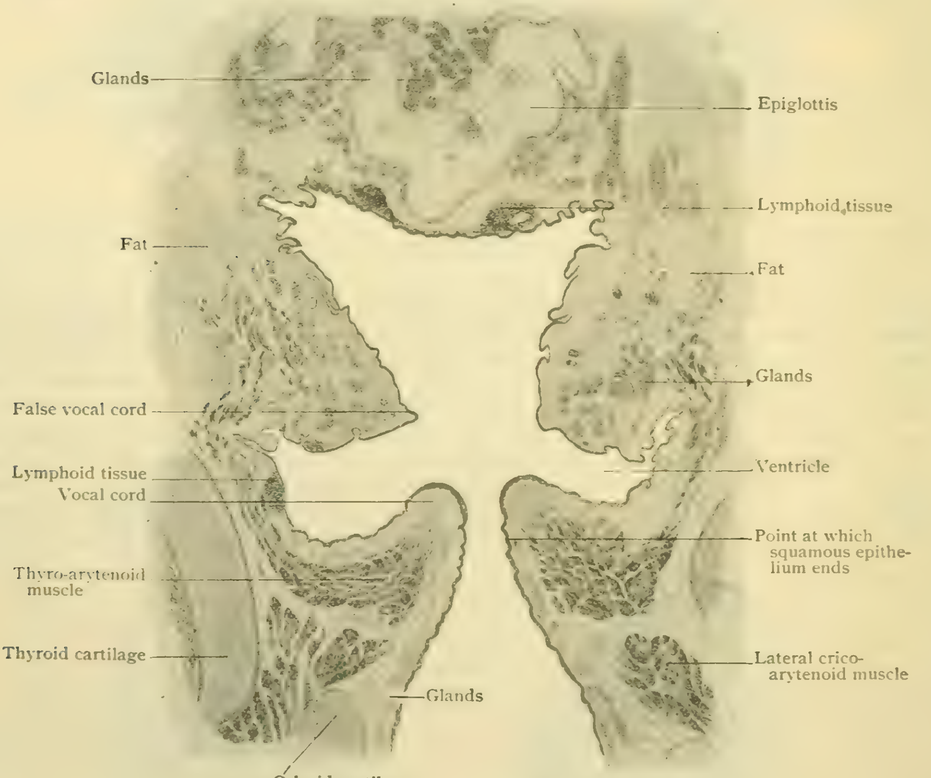
cords end at the vocal processes, a considerable part of the chink of the glottis is bounded by these cartilages. The posterior part between them is called the *respiratory*, and the anterior, between the cords, the *vocal* part. According to Moura,[2] the entire length of the chink in the male is 23 mm., of which the vocal part is 15.5 mm.

[1] Archiv f. Anat. u. Phys., Anat. Abth., 1889.
[2] Bull. de l'Acad. de Médecine, Paris, 1879.

and the respiratory 7.5 mm. In the female the length is 17 mm., and the respective parts measure 11.5 mm. and 5.5 mm. The elasticity of the vocal part, however, allows it to stretch. The shape of the rima glottidis varies with the position of the arytenoids, and the theoretically straight lines of its borders may both be approximated and drawn asunder, and, moreover, may be bent at the junction of the two parts.

The *ventricle* or *laryngeal sinus* (ventriculus laryngis) is a pouch, lined with mucous membrane, opening into the larynx between the true and false cords of each side. The horizontal elliptical opening has a breadth (vertically) of from 3–6 mm. As has been stated, the upper surface of the true cord slants downward and outward; but the ventricle is partly under cover of the false cord, around which it ascends. The ascent may be due to an *appendix of the ventricle* (Fig. 1551), which may be an almost separate cavity connected with the front of the ventricle by a slit or an irregular

FIG. 1551.



Frontal section of larynx, about middle of vocal cords. × 3.

opening. Not rarely, however, it is without separation from the rest of the ventricle. It may ascend to a height of 15 mm. from the bottom of the ventricle. These cavities are compressed laterally, and situated in the thickness of the wall of the larynx proper, internal to the fossa pyriformis. According to Rüdinger, the ventricles are relatively much larger in the male. Occasionally cases of great over-development of the ventricles are met with. They may even perforate the thyro-hyoid membrane. This is analogous to the sacs of the anthropoid apes. Brösike[1] has seen a median pouch perforating the thyroid in the region of the vocal cords. A similar structure occurs in the horse, ass, and mule. The function of the true cords is to change the size and shape of the glottis both during respiration and phonation, and to cause sound by their vibrations, which depend in part on their tension. When drawn into

[1] Virchow's Archiv, Bd. xcviii., 1884.

contact, they close the glottis and prevent the entrance of air, but from their shape they seem unfitted to prevent its exit. This, according to the general teaching, is accomplished by the valvular action of the false cords, to which the ventricles contribute, but it is not clear that they contain the musculature necessary for such action.

The **infraglottic region** (**conus elasticus**) expands laterally beneath the true cords so as to become practically circular before reaching the lower border of the cricoid. The little fossa beneath the arytenoid cartilages is the upper part of this region, which is broadest between them.

The **mucous membrane of the larynx** is in parts thin and tightly bound down to the cartilages beneath it, and elsewhere thick, with much subjacent areolar tissue. It is very intimately connected to the free part of the epiglottis and to all of its intralaryngeal surface, but less so to the anterior part near the tongue. It is closely applied to the arytenoids and also to the lower part of the cricoid. It is thin and adheres very tightly to the true vocal cords along the ligament. In the aryepiglottic

FIG. 1552.

Frontal section of larynx through vocal processes of arytenoid cartilages. × 3.

folds it is lax and redundant. Beginning at the base of the epiglottis, the epithelium covering the mucous membrane is of the stratified ciliated columnar type throughout the larynx, with the exception of that over the vocal cords, false as well as true, which abruptly changes to stratified squamous. Mucus-secreting goblet-cells occur in varying profusion among the columnar elements. The superficial layers of the fibro-elastic stroma of the mucous membrane contain many lymphocytes, which in places are so numerous that the tunica propria resembles lymphoid tissue.

The *glands* are very general. They occupy pits in the epiglottis, are very numerous and large in the false cords, and plentiful in the walls of the ventricles. They do not occur on the upper surface of the true cords within 3 or 4 mm. of the free edges, but in the infraglottic region form nearly a continuous shallow layer to within 2 or 3 mm. of the free edge of the vocal cord. The laryngeal glands are tubulo-alveolar in form and mixed mucous in type, in addition to the mucus-producing cells containing groups of serous elements.

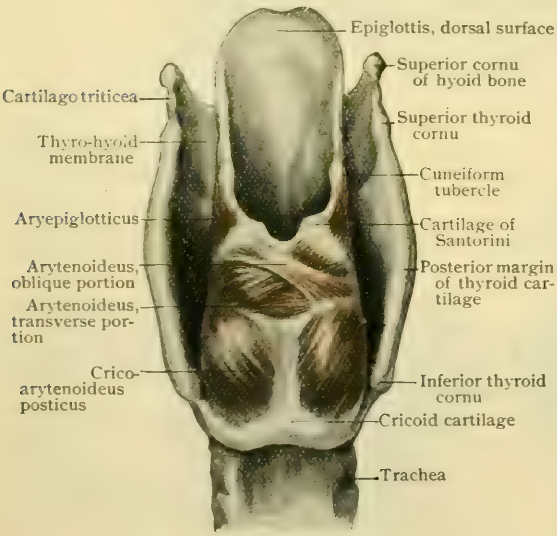
Lymphoid tissue, as distinct nodules, is occasionally observed on the posterior

surface of the epiglottis and the side and back walls of the larynx, its most usual position being the ventricle (Fig. 1551). Within the laryngeal pouch the lymphoid tissue is so constant and plentiful that *laryngeal tonsil* has been suggested (Fraenkel) as an appropriate name for these collections.

THE MUSCLES OF THE LARYNX.

The extrinsic muscles of the larynx should include those going to the hyoid bone, which is physiologically a part of this apparatus. These have been described in the systematic consideration of the Muscular System (page 543). The intrinsic muscles are the *crico-thyroid*, the *posterior crico-arytenoid*, the *lateral crico-arytenoid*, the *thyro-arytenoid*, and the *arytenoid*. All of these, except the last, are in pairs. From a physiological stand-point these muscles may be divided into three groups: the *constrictors*, including both the adductors of the cords and those which draw together the supraglottic portion of the larynx; the *dilators*, which abduct the cords; and those which *modify the tension* of the cords without necessarily approximating or separating them. The constrictors are the lateral crico-arytenoids, the thyro-arytenoids, and the arytenoid. The dilators are the posterior crico-arytenoids. Those modifying the tension of the cords are the crico-thyroids, which stretch them, and a part of the thyro-arytenoids, which relax them. Moreover, many of these muscles, even antagonistic ones, when acting together may be considered as parts of a sphincter. The laryngeal muscles are extremely variable, especially the thyro-arytenoid, detached fibres of which have been described as the thyro-epiglottideus.

Fig. 1553.



Muscles of larynx from behind.

The **crico-thyroid muscle** (Fig. 1510) is well defined, passing upward and outward from the anterior ring of the cricoid to the under border and the inferior horns of the thyroid. The *origin* is from the whole of the anterior surface of the arch, except for a slight interval between the muscles. The internal fibres are nearly vertical and the lateral ones nearly horizontal. The *insertion* is into the lower border of the thyroid cartilage from a point a few millimetres in front of the inferior tubercle to all the rest of the lower border and the front of the inferior horn. It often extends a little onto the posterior surface of the ala. The muscle is frequently divided into a superficial and a deep part. The distinction may be very striking, or may be wanting. The superficial is the more internal vertical part, which conceals a little of the origin of the deeper. The crico-thyroid may be continuous by some fibres with the inferior constrictor of the pharynx. It may descend to the first ring of the trachea, and it may give off fibres to the capsule of the thyroid body. Occasionally the muscles of the two sides are connected at the lower border of the cricoid. In extreme cases each may cross the median line.

Action.—This muscle is a tensor of the vocal cords by separating their points of attachment on the thyroid cartilage from those on the arytenoids. Although the conventional names of origin and insertion have been used, the more movable of the two cartilages is the cricoid, and the action of the muscles is to raise its anterior arch, thereby tipping the posterior plate with the arytenoids backward, and so stretching the cords. While the thyroid can be held fixed by many muscles, the only extrinsic one attached to the cricoid is a part of the inferior constrictor of the pharynx, so that

upon the cricoid cartilage devolves the whole, or nearly the whole of the movement. Although the movement is generally described as rotation on a transverse axis passing through the two crico-thyroid joints, the articulation is of so vague a character that a great deal of sliding occurs.

The **posterior crico-arytenoid muscle** (Fig. 1554) is very distinct and occupies the hollow on either side of the median ridge on the back of the cricoid cartilage. It is triangular, with rounded angles at the base, which is at the ridge, and the third sharp angle at the posterior border and upper aspect of the muscular process of the arytenoid. The *origin* is not from the whole of the fossa on the cricoid, but chiefly from the region of the ridge whence it springs by tendinous fibres. It arises also from the lower part of the cricoid, but not from the part near the arytenoid. It passes over the capsule of the joint, with which it is intimately fused, and is *inserted* as above stated, some of its fibres becoming tendinous.

Action.—It pulls the muscular process downward and inward, thus raising and everting the vocal process and consequently enlarging the cleft of the glottis.

Two occasional small muscles in the neighborhood of the inferior horn of the thyroid are probably aberrant bundles of the posterior crico-arytenoid. One, the *posterior crico-thyroid*, slightly diverging from the lower external fibres, runs from the back of the cricoid upward and outward to the internal aspect of the inferior horn of the thyroid. The other, the *posterior thyro-arytenoid*, runs from the lower horn upward to be inserted with the posterior crico-arytenoid into the muscular process.

The **lateral crico-arytenoid muscle** (Fig. 1554), of an elongated triangular form, *arises* from the upper border of the lateral part of the cricoid and from the ascending edge of the plate as far as the arytenoid joint. It also may have fibres springing from the crico-thyroid membrane. It is *inserted* into the front of the muscular process. This muscle is less well defined than the posterior crico-thyroid, and may be more or less fused with the thyro-arytenoid, on the one hand, and the crico-thyroid, on the other.

Action.—It pulls the muscular process forward, thereby bringing the vocal cord nearer to its fellow.

The **thyro-arytenoid muscle** (Fig. 1554) *arises* from the inner surface of the thyroid, just outside the entering angle, from the level of the true cord to the lower border. At the side it arises from a part of the crico-thyroid membrane, and may there be continuous with the lateral crico-arytenoid. It runs backward and is *inserted* into the upper surface of the vocal process of the arytenoid and into the antero-external surface of that cartilage. It is convenient to speak of an internal and an external part, but there is no separation between them. The *internal portion* (**m. thyreoarytaenoideus vocalis**) is a prismatic mass, triangular on section (Fig. 1551), forming the bulk of the true cord, with one of its angles against the ligament in the free edge. Ludwig taught that fibres diverged from the body of this muscle to be inserted successively into the ligamentous band of the vocal cord, which thus resembled the tendon of a muscle receiving oblique fibres along its side. These were supposed to modify its tension indefinitely by pulling upon it at various points. This view has been denied by Luschka, and the point remains undecided. Jacobson[1] found on

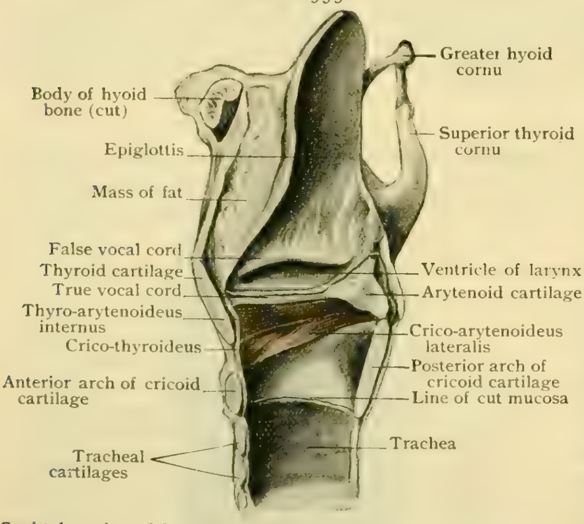
FIG. 1554.

Muscles of larynx, lateral view after partial removal of right thyroid ala.

[1] Archiv f. mikro. Anat., Bd. xxix., 1887.

microscopic sections that fibres were often inserted obliquely into the cord and into the end of the vocal process. There was, however, much variation, and in some cases no such fibres were found. Our own observations incline us to look upon such fibres as possible, but probably in the ordinary larynx they are few and far between. The *external portion* (Fig. 1554) is a thin membrane on the outer side of the ventricle, with its fibres spreading upward and backward towards the aryepiglottic fold. Some few fibres are, or may be, found in the false cord, and some occasionally arch over the ventricle. The external portion is very irregular and inclined to give off aberrant bundles. The *superior thyro-arytenoid* is a common one. It arises from the inner side of the ala of the thyroid, near the top, a little outside of the notch, and runs downward and backward to the top and anterior aspect of the vocal process, resting on the outer side of the external part of the thyro-arytenoid and crossing it at right angles. It consists of long parallel fibres and varies much in size. The *thyro-epiglottic muscle* is simply fibres of the system of the thyro-arytenoid that pass upward to the side of the epiglottis. We incline to consider the *aryepiglottic muscle* (Fig. 1554)—a little bundle extending from the side of the arytenoid to the epiglottis in the edge of the fold—a part of this same system.

Fig. 1555.



Sagittal section of larynx from within; mucous membrane has been removed from vocal cord to lower level of cricoid cartilage.

Action.—That of the internal part of the thyro-arytenoid is to relax the vocal cords by approximating their ends; if, however, the fibres inserted into the cords be worth considering, this action must be modified by the stretching of parts of the cords while others are relaxed. The irregularity of this arrangement is quite in harmony with the endless variations of the human voice. The shape of the walls below the true cords must also be modified by the swelling of the contracting muscle. The action of the outer portion of this muscle must be in the main that of a constrictor of the supraglottic region. It is possible that when the cords are abducted some of the fibres inserted into the muscular processes may act as adductors.

The **arytenoid muscle** (**m. interarytaenoideus**) is a mass of fibres running transversely between the hollows on the posterior surfaces of the arytenoid cartilages, which it fills (Fig. 1553). There is usually a superficial *oblique* part of this muscle which, when well developed, is formed by two bands crossing each other like the arms of an X placed on its side. Each arm starts from the muscular process of the arytenoid and crosses to the summit of the arytenoid of the opposite side. Here it may end or be continuous with the fibres of the aryepiglottic muscle, which ascend to the epiglottis. One or both arms may be wanting, and this part may be more or less fused with the deeper transverse fibres.

Action.—It draws the arytenoid cartilages together, and is, moreover, an important part of the sphincter-like arrangement.

Vessels.—The *arteries* are the superior laryngeal and the crico-thyroid from the superior thyroid artery and the inferior laryngeal from the inferior thyroid artery. The superior laryngeal pierces the thyro-hyoid membrane some 5 mm. from the superior horn of the thyroid and about midway between the top and the bottom. After giving off an epiglottic branch, which on its way supplies the areolar tissue anterior to the epiglottis, the vessel runs downward and backward under cover of the ala of the thyroid to its distribution in the upper part of the larynx. The crico-

thyroid branch meets its fellow so as to form an arch across the median line and sends perforating branches into the larynx through the crico-thyroid membrane. The inferior laryngeal from the inferior thyroid reaches the region of the back of the larynx from the side. It anastomoses with the superior laryngeal and sometimes sends branches through or into the arytenoid muscle. The vocal cords possess relatively few blood-vessels.

The *veins* correspond in the main to the arteries, but, owing to their greater size and freer anastomoses, they seem in more immediate relation with those of the thyroid body. Moreover, they tend to form a median descending vessel in the front of the neck. There is a plexus on the pharyngeal side of the back of the larynx which communicates through the folds at the sides of the entrance with the veins of the dorsum of the tongue. The inferior laryngeal vein empties into the inferior thyroid through a circular plexus around the entrance of the trachea.

The *lymphatics* of each side empty into two chief vessels, of which the superior pierces the thyro-hyoid membrane, carrying the lymph from the supraglottic region to the nodes under or near the sterno-mastoid. The inferior vessel descends under the mucous membrane outward and backward to the nodes along the posterior surface of the trachea. It may, however, open into an inconstant node in front of the crico-thyroid membrane. This node occurs in 44 per cent. of adults and in 57 per cent. of children. It may be double.[1]

FIG. 1556.

Cast of cavity of larynx and adjacent part of trachea; anterior aspect.

Nerves.—These are the superior and the inferior laryngeal nerves, both from the vagus. The superior, on reaching the thyro-hyoid membrane, divides into an external and an internal branch. The external continues downward and forward to the crico-thyroid muscle, which it supplies. It is in relation with the pharyngeal plexus and the superior sympathetic ganglion. The internal branch pierces the membrane together with the superior laryngeal artery, and supplies the greater part of the mucous membrane. Its ramifications are in two groups: ascending ones to the epiglottis, the region just before it, and to the aryepiglottic folds; others passing to the mucous membrane within the larynx and to that of the posterior surface looking towards the pharynx. The inferior laryngeal, ascending by the side of the back of the trachea, divides into two branches. The branch nearer the median line innervates the posterior crico-arytenoid and the arytenoid muscles. Its fibres, in part sensory, enter into communication with those of the superior laryngeal. The other branch of the inferior laryngeal goes to the other intrinsic muscles of the larynx. Thus the superior laryngeal divides into a motor branch that ends in one muscle, and a sensory division which plays the greater part in supplying the mucous membrane. The inferior laryngeal is also a mixed nerve, but chiefly motor. It supplies all the other muscles and helps to supply the mucous membrane. A remarkable peculiarity of the sensory nerves is a tendency to cross the median line, so that certain regions are reached from both sides.

The general teaching by English anatomists has been that the superior laryngeal is as above stated and that the inferior is purely motor. Exner[2] made observations, in part confirmed and in part disputed, to the effect that both nerves are mixed, supplying both muscles and mucous membrane (the superior supplying, in part at least, certain muscles within the larynx), and that both motor and sensory fibres cross the median line, so that some muscles receive the corresponding nerve of both sides. Moreover, he found in some animals a *middle laryngeal nerve* from the pharyngeal branch of the vagus, of which the analogue exists in man, in whom it goes, together with the superior laryngeal, to the crico-thyroid muscle of both sides.

[1] Nicolas in Poirier's Traité d'Anatomie Humaine.
[2] Vienna Akad. Sitzungsbericht, 1884.

In the above description we coincide with Onödi,[1] who denies entirely the existence of the middle laryngeal in man.

The endings of the numerous sensory nerves in the mucous membrane, as described by Retzius, Fusari, Ploschko, and others, include free terminations between the epithelial cells and subepithelial end-arborizations. According to Ploschko, special end-organs, composed of columnar cells surrounded by delicate nerve-fibrillæ, exist within the true vocal cords. Taste-buds occur not only on the posterior surface of the epiglottis, but also within the laryngeal mucous membrane in the vicinity of the arytenoid cartilages.

Position and Relations of the Larynx.—The larynx forms a part of the anterior wall of the pharynx and rests, therefore, against its posterior wall. In the adult male the tip of the epiglottis is opposite the lower border of the third cervical vertebra and the lower end of the cricoid opposite some part of the seventh vertebra. Thus in man it covers about four vertebral bodies, with the intervening disks. It is small in the female and rather higher. Mehnert[2] believes that in the living body in the upright position the cricoid is about one vertebra lower than it is after death in the recumbent position. Individual variation is marked, as is shown by the results compiled from the researches of Taguki.[3] Thus in thirty-five men the lower border of the cricoid was opposite or below the seventh vertebra twenty-nine times, but in thirty-three women only twenty-one times. It was above it six times in men and twelve times in women ; in one case (male) it was as high as the fifth vertebra.

Anteriorly the larynx lies beneath the middle layer of the cervical fascia. The lobes of the thyroid rest on either side against the cricoid and thyroid. The larynx as a whole can be raised and depressed by muscles, and changes its position with the movements of the spine. Thus, when the neck is bent, it falls 1 cm., and rises 3 cm. when the neck is extended. When the head is turned to one side, the hyoid is twisted less than the head, but more than the larynx, although the latter and the trachea may share in the movement. The larynx may be displaced sideways by external pressure.

Changes with Age and Sexual Differences.—At birth the larynx is very small, but may be said to be relatively larger than later. The sharp angle of the thyroid cartilage is entirely wanting. The larynx grows gradually up to puberty, when it takes on a sudden expansion, which occurs in both sexes, but is much more marked in the male. According to Luschka, it doubles in man and increases by less than half in woman. The most marked sexual difference is the size and prominence of the thyroid cartilage in the male. The duration of the process by which the larynx of a child changes into that of an adult may, according to F. Merkel, be as much as two years, and, in fact, changes may occur throughout growth. In the fœtus the position of the larynx is very high. At birth the lower border of the cricoid is opposite the lower border of the fourth vertebra. Symington found it at six years at the lower border of the fifth and at thirteen at the top of the seventh. Probably it reaches what may be called its permanent position at about puberty. Mehnert, however, finds from his observations on the living that the descent continues till about thirty, when there is a great retardation, or even a suspension, of the process till about sixty, when it goes on again with renewed activity. According to him, the cricoid may ultimately reach the second or even the third thoracic vertebra. It is to be noted that, while the earlier descent is a physiological process, that of old age is a degenerative one, depending in part on changes in the spine and on the loss of elasticity of the tissues.

PRACTICAL CONSIDERATIONS: THE LARYNX.

The Air-Passages.—The *hyoid bone* is closely contiguous to the opening of the larynx, and as its injuries derive their chief surgical importance from that relation, they are considered here.

Fracture of the hyoid results from compression by the grasp of a hand, by the rope in cases of hanging, or from a direct blow. It usually occurs near the junction of the greater cornu with the body of the bone. Displacement is not apt to be

[1] Die Anatomie und Physiologie der Kehlkopfnerven, Berlin, 1902.
[2] Ueber topographische Altersveränderungen des Atmungsapparates, 1901.
[3] Archiv f. Anat. u. Phys., Anat. Abth., 1889.

marked, because the great horn is held above by the digastric aponeurosis and the hyo-glossus muscle and below by the thyro-hyoid ligament and muscle. Exceptionally the middle constrictor of the pharynx may draw it somewhat backward and inward. The attachments to the hyoid of the constrictor and of the hyo-glossus and genio-hyo-glossus invariably make deglutition and speech painful after this fracture, while the genio-hyoid and digastric, by their contraction, cause pain on opening the mouth. The associated swelling may involve the epiglottic mucous membrane and, spreading thence, give rise to serious dyspnœa.

The *thyro-hyoid membrane*, springing from the posterior upper margin of the hyoid bone and attached to the upper border of the thyroid cartilage, has interposed between its anterior surface and the posterior face of the body of the hyoid a bursa which descends below the lower border of that bone, and when enlarged forms a cystic swelling situated in the median line of the neck, just beneath the hyoid. Thyro-lingual cysts are sometimes found in the same situation.

A similar cystic swelling, lined with columnar epithelium and occupying the same region, is referable to the persistence of the fœtal thyro-lingual duct. At the upper end of that duct such a cyst would lie in the mid-line of the tongue between the two genio-hyo-glossi muscles. At the lower end it would lie over the thyroid or the cricoid cartilage. The sinuses formed by the bursting of such cysts, or originally by the persistence of portions of the thyro-lingual duct, are obstinate, and, on account of their epithelial lining, must be dissected out completely to secure healing.

The lower portion of the thyro-hyoid membrane is covered in the mid-line by cervical fascia and skin, laterally by the sterno-hyoid and thyro-hyoid muscles.

Cut-throat wounds of the neck, especially if suicidal, are apt to pass through this membrane, which is made tense when the head is thrown backward, and, if they are deep, will divide the inferior constrictor, open the pharynx, and possibly wound or sever the epiglottis near its base, first passing through the cellulo-adipose tissue that intervenes. If the wound is not immediately beneath the lower border of the hyoid, it may divide the internal branches of the superior laryngeal nerve, leading ultimately to a pneumonia from the inspiration of foreign matter. In *infrahyoid pharyngotomy* such a transverse wound, hugging the lower edge of the hyoid, gives access to the base of the pharynx and the supraglottideal region.

Above the hyoid a cut-throat wound would divide the tongue muscles and enter the mouth. Below the thyroid it would pass through the crico-thyroid membrane and open the larynx. Still lower the trachea would be incised or severed.

The great vessels often escape in suicidal wounds, as the usual position of the head in extreme extension increases the projection of the laryngeal apparatus and therefore the depth of the vessels from the surface. One reason for their escape when the air-passages below the glottis are opened may be that the sudden rush of air from the lungs and consequent collapse of the chest-walls deprive the muscles running from the thorax to the humerus of their fixed point of support, and that the arm necessarily drops (Hilton). Death may be caused, however, by hemorrhage from the superior thyroid or the lingual artery, or even from the crico-thyroid if the blood enters the larynx or trachea; or may result from suffocation produced by the dropping backward of the tongue after division of the genio-hyoid, hyo-glossus, and genio-hyo-glossus muscles, or by the occlusion of the glottis by a partly divided epiglottis or arytenoid.

Fracture of the thyroid or cricoid cartilage may occur from the same causes that produce fracture of the hyoid bone. The thyroid, on account of its greater prominence, suffers more frequently. Fractures of the thyroid are seen oftener in males than in females, because (*a*) in the former it is relatively more prominent; (*b*) the process of ossification—which, in common with other hyaline cartilages, it undergoes after adult life has been reached—is more complete in them; and (*c*) males are oftener exposed to violence.

The symptoms depend for their gravity chiefly upon the degree of involvement of the laryngeal mucous membrane. If that is wounded, bloody expectoration, aphonia, and dyspnœa are present, and tracheotomy may be urgently indicated. In any event, deglutition is painful. The voice is usually altered, and there is apt to be some external deformity. Crepitus may be present, but should be distinguished from the

sound produced by moving the normal larynx laterally, and caused by the friction between the somewhat irregular anterior surface of the vertebral column and the posterior border of the thyroid, the corresponding surface of the cricoid, and the lower part of the pharynx, which move together. This normal crepitus disappears in retropharyngeal abscess, but persists in retrolaryngeal abscess (Allen). It should be remembered that the superior cornua of the thyroid are sometimes found separate from the body.

The *cricoid* and, much more rarely, the *thyroid* and *arytenoid* cartilages may be the subject of *perichondritis* secondary to ulceration (typhoidal, cancerous, syphilitic, or tuberculous) of the interior of the larynx. In the case of the cricoid it is asserted that the condition may result from the pressure of the posterior aspect of the cartilage against the spine in very debilitated subjects, or from the traumatism caused by the frequent passage of an œsophageal bougie (Pearce Gould). The origin of the inferior constrictor from the cricoid accounts for the pharyngeal spasm and dysphagia said to accompany disease of this cartilage (Gibbs).

Allen says that the cricoid is relatively more prominent in women than in men, and that it is often the site to which abnormal sensations originating in the pharynx are referred, because in such conditions deglutition is painful, and since the cricoid lies at the lower part of the pharynx, its motions determine a greater amount of distress than do the corresponding motions at any other part of the throat.

The *epiglottis* is not infrequently affected by syphilis, and is also, although more rarely, the seat of tuberculous lesions, and may be extensively ulcerated or may become necrotic. The danger of such cases results usually from the accompanying œdema (*vide infra*), but in rare instances a sloughing and wholly or partially separated epiglottis may directly occlude the laryngeal aperture.

Infection originating in disease of the epiglottis may involve the cellulo-adipose tissue between its base and the thyro-hyoid membrane, giving rise to a *thyro-hyoid abscess* which may extend towards the mouth and project in the groove between the root of the tongue and the epiglottis. Such an abscess may also follow primary infection of either the tongue or the thyroid. It is very apt to cause *œdema of the glottis*. The condition known by this name may occur in any form of laryngitis, or by extension of inflammation from the mouth, tongue, or pharynx, or as a result of trauma or of wound, scald, or the application of local irritants. It involves the glottis only secondarily. The thin mucous membrane covering the true vocal cords and the arytenoids is so closely applied to them, and the subcutaneous connective tissue is so scanty, that there is no opportunity for much exudation. But in the supraglottidean region the mucosa is thick and the submucosa plentiful, especially over the aryteno-epiglottidean folds, and almost equally so in the ventricles and over the false cords and the posterior surface of the epiglottis. Effusion of serum and swelling are thus favored and, according to their degree, will produce hoarseness, aphonia, dyspnœa, cyanosis, or positive suffocation. In some cases of œdematous laryngitis the swelling affects chiefly the region below the glottis (*subglottic œdema*) and causes the same symptoms. This is rarer and is attended by less effusion on account of the relatively closer association of the mucosa and the cricoid cartilage.

The mucous glands of the larynx which supply the moisture needed in normal phonation are sometimes inflamed as an indirect result of the over-use of the voice, —as in clergymen, costermongers, public speakers, etc. The increased volume of air taken in through the mouth dries up the mucous surface of the larynx, and the effort to compensate for this may result in such irritation of the glands and mucosa as to cause a form of chronic laryngitis,—"clergyman's sore throat."

The *rima glottidis*,—the aperture of the *glottis*,—the narrowest portion of the air-passages, measures a little less than one inch antero-posteriorly in the adult male. Its transverse diameter at its widest portion is about one-third of an inch. In the male before puberty, and in the female, these measurements are about one-fourth less. They are important in reference to the introduction of instruments and the arrest of foreign bodies (*vide infra*).

The level of the glottis—*i.e.*, of the true vocal cords—is a little above the middle of the anterior margin of the thyroid cartilage.

The shape of the aperture varies. It is *linear* when a high note is produced in speaking or singing, *triangular* (with the apex forward, equal sides and a narrow

base) during quiet respiration, and *diamond-shaped* (with the posterior angle cut off) in forced breathing. As various forms of ulceration (tuberculous, syphilitic, diphtheritic) may affect the mucous membrane covering the true vocal cords, or the cords themselves, or the structures in their immediate vicinity (especially the aryteno-epiglottidean and interarytenoid folds and the ventricular bands), and as cicatrization with subsequent contraction of scar tissue may follow, diminution of the calibre of the *rima glottidis* (stricture) is not uncommon.

Polyps, warty growths, and other benign tumors are found in the vicinity of the vocal cords, and if they cannot be removed by intralaryngeal operation, may necessitate thyrotomy. Subglottic tumors are relatively infrequent. They often spring from the inferior surface of the vocal cords, intraglottic growths from the free border of the anterior part of the vocal cords, and supraglottic growths from the epiglottis and the aryteno-epiglottic folds (Delavan).

Spasm of the glottis (laryngismus stridulus) may occur, especially in infancy, from reflex irritation, and may cause great dyspnœa or may even result fatally. The irritation is conveyed chiefly to the inferior laryngeal nerves through the pneumogastrics, if the cause is undigested food; through the trifacial, if the irritation is associated with dentition; or through the spinal accessory, if vertebral disease is present.

The different forms of laryngeal *paralysis* should be studied in connection with the physiology of phonation. Some of the chief anatomical considerations may be indicated by the following classification, which is, however, necessarily incomplete, as failing to include the central causes of paralysis—as in bulbar palsy—and those due to toxæmia, as the post-diphtheritic.

1. *Those due to direct or indirect involvement of the superior laryngeal nerves.*

(*a*) *Sensory and thyro-epiglottic*—or *aryepiglottic—paralysis*, characterized by a tendency of food or liquids to enter the larynx, by dysphagia, by immobility of the epiglottis, and by diminished sensation in both the pharyngeal and laryngeal mucous membranes, would suggest especial implication of the internal branch.

(*b*) *Crico-thyroid and thyro-arytenoid paralysis*, causing loss of tension in the vocal cords, inability to regulate and control the voice, and with evidence of the want of action of the crico-thyroids detected by the finger placed on either side of the crico-thyroid interval externally during phonation (Agnew), may, in some cases, be referred anatomically to the external branch.

2. *Those due to involvement of the inferior laryngeal nerves.*

(*a*) *Lateral crico-arytenoid paralysis*, causing separation of the vocal cords, with more or less complete aphonia, may be due to implication of the external branch. In many cases there will be evidence of the existence of innominate or aortic aneurism, thyroid or bronchial glandular enlargement, carcinoma of the œsophagus, or some other condition competent to produce pressure on the nerve. The paralysis may be unilateral and attended only by hoarseness and partial loss of voice.

(*b*) In *posterior crico-arytenoid paralysis* (abductor paralysis) the loss of power in the abductors permits the lateral crico-arytenoid muscles to narrow the glottis into a mere fissure, so that inspiration becomes stridulous and dyspnœa is marked; the voice is not materially interfered with. The condition may be due to intra- or extralaryngeal growths, or to inflammatory conditions, possibly causing pressure on the inner branch. It may be unilateral and due to aneurism.

It should be understood that the relation of these paralyses to the external and internal branches of the superior and inferior laryngeal nerves cannot be demonstrated clinically with definiteness. Pressure on the main trunk of either nerve, tabes, hysteria, toxæmia, and other central or general causes may produce any of these forms of paralysis.

In *intubation* of the larynx (employed in some forms of acute stenosis, as in diphtheria or œdematous laryngitis) an irregular cylindrical tube with a fusiform enlargement and an expanded upper extremity—so that it may rest on the ventricular bands—is carried into place by an "introducer" and is guided by the left forefinger of the surgeon, which is passed over the dorsum of the tongue to the epiglottis and made to recognize the laryngeal opening.

Thyrotomy is sometimes done for the removal of intralaryngeal tumors. The incision extends from the thyro-hyoid space to the top of the cricoid cartilage, is

directly in the median line, and divides skin, superficial and deep fascia, the junction of the alæ of the thyroid, and the mucous membrane of the larynx.

Laryngotomy (through the crico-thyroid membrane) may be indicated in adults for impending suffocation from any form of obstruction of the glottis. In children the space is too small. A median incision beginning over the thyroid cartilage is carried to half an inch below the cricoid cartilage. The skin and fasciæ having been divided, the crico-thyroid membrane is exposed between the two crico-thyroid muscles, which sometimes require separation. The crico-thyroid arteries may be exceptionally large, and in any event should usually be ligated, although in cases of great emergency that step may be postponed until the membrane has been divided. This may be done by a transverse incision to minimize the risk of hemorrhage. The nearness of the vocal cords to the opening renders this operation unsuitable to cases in which a tracheotomy tube must be worn for some time.

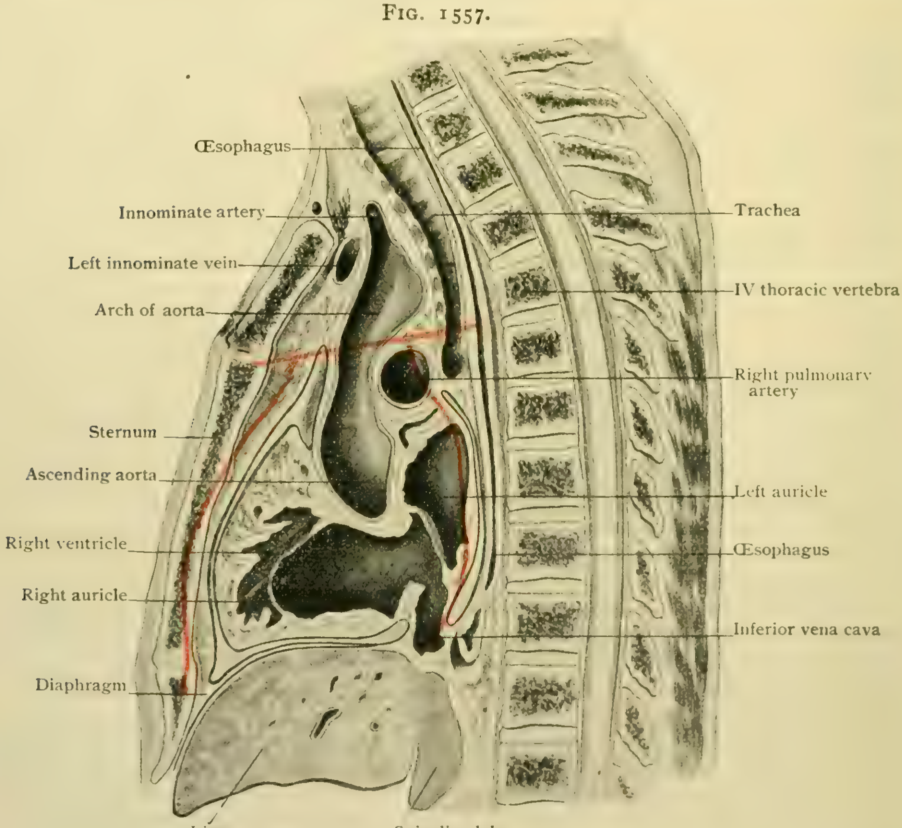
Excision of the larynx, occasionally done for malignant disease, necessitates the separation of the larynx from the sterno-thyroid and thyro-hyoid muscles laterally, from the inferior constrictor and the hyoid bone above, from the trachea below, and from the pharynx and œsophagus posteriorly. The superior and inferior thyroid arteries, or their branches, and the superior and inferior laryngeal nerves will be divided.

For landmarks of the neck, see page 554.

THE SUBDIVISIONS OF THE THORAX.

As the entire respiratory apparatus, with the exception of the larynx and a part of the trachea, is within the thorax, it is advisable to describe the subdivisions of that

FIG. 1557.



Median sagittal section of formalin subject; relative position of mediastinal spaces outlined in red.

cavity. The lungs, enveloped in their serous coverings, the pleuræ, fill the greater part of the sides of the chest external to planes passing forward from the sides of the

bodies of the vertebræ to the sides of the sternum. The median space between the pleuræ is called the *mediastinal space*, and is subdivided into four parts called *mediastina*. The above statement of the lateral boundaries of the mediastinal space is only a general one, for in the middle the mediastinal space expands beyond them and in front is restricted by the advance of the pleuræ beneath the sternum. The *superior mediastinum* is that part of the space above a plane passing from the disk below the fourth thoracic vertebra to the junction of the first and second pieces of the sternum. This is occupied by the upper part of the thymus, the arch of the aorta and the vessels rising from it, the innominate veins, and the superior vena cava. It is traversed by the trachea and œsophagus, the thoracic duct, the pneumogastric, the phrenic, and the sympathetic nerves. The region below the above mentioned plane is subdivided by the pericardial sac into an anterior, middle, and posterior compartment. The *middle mediastinum* is occupied by the heart within the pericardium. The roots of the lungs are partly in this and in the superior mediastinum. The shallow *anterior mediastinum* is between the middle one and the sternum. It contains the lower part of the thymus, a few lymph-nodes, fat, and areolar tissue. The *posterior mediastinum*, between the spine and the middle mediastinum, contains the œsophagus, the aorta, the thoracic duct, the azygos veins, the pneumogastric and sympathetic nerves.

PRACTICAL CONSIDERATIONS: THE MEDIASTINUM.

Wounds penetrating the mediastinum, even when they do not involve the air-passages, may, in consequence of air being drawn into the space by respiratory movements, be followed by general emphysema or by *mediastinal emphysema*. This condition is not infrequent after tracheotomy, the conditions favoring its production being free division of the deep fascia, continued obstruction of the air-passages, and labored inspiration.

If there is *hemorrhage* into the mediastinal space, or if *abscess* results from infection of a clot, or from extension of tuberculous disease of the bronchial glands, or as a sequel of typhoid fever, the anatomical symptoms will be those of pressure (*vide infra*). In the presence of a large abscess, pus may perforate the sternum by erosion or may find its way out through the little circular openings sometimes found as a result of developmental failure (page 168). It may also be evacuated through an intercostal space or into the trachea or œsophagus.

Tumors may be malignant or benign (lymphomata, dermoids, hydatids, fibromata), the order of mention being that of their relative frequency. The chief symptoms are those due to intrathoracic pressure, which is, of course, not uniform, and varies with the origin, extent, and density of the tumor, but in its effects upon the separate structures contained within the mediastinum affords a reasonably accurate basis for an anatomical classification of the clinical phenomena of these growths.

1. Compression of veins. (*a*) The superior vena cava: cyanosis or lividity of the face; dilatation of the superficial veins of the neck, face, and head; œdema of the same region; epistaxis; disturbances of vision or amaurosis; tinnitus aurium or total deafness; cerebral effusion or hemorrhage; œdema of one or both arms. (*b*) The greater azygos vein: dilatation first of the right and later of the left intercostal veins; œdema of the upper part of the chest-wall; right-sided hydrothorax with secondary or later effusion into the left pleura (Stengel); pericardial effusion; mediastinal effusion. (*c*) The pulmonary vein: œdema of the lung; hæmoptysis.

2. Compression of arteries (much rarer than of venous channels). (*a*) The aorta: inequality in the radial pulses; engorgement of the left side of the heart; pulsation of the growth, if it is visible or palpable (as at the suprasternal notch or over the sternal ends of the clavicles); pallor; giddiness; anginose pains. (*b*) The pulmonary artery: distention of the right heart; dyspnœa; ultimately—as a secondary result of the cardiac condition—ascites; œdema of the lower extremities; general anasarca.

3. Compression of nerves. (*a*) The pneumogastric: irregular heart action with marked rapidity or slowness; syncope; vomiting; hiccough; pharyngeal or laryngeal spasm or paralysis; dysphagia; spasmodic cough. (*b*) The inferior laryn-

geal nerve : posterior crico-arytenoid paralysis with stridor and inspiratory dyspnœa (page 1273). (*c*) The sympathetic : various disturbances of vision ; irregular pupils.

4. Compression of the thoracic duct. Emaciation ; chylo-thorax ; chylous ascites ; mediastinal effusion of chyle.

5. Compression of the air-passages. (*a*) The trachea : stridor ; dyspnœa. (*b*) The bronchi : feeble breath-sounds ; dyspnœa ; recession of the suprasternal and supraclavicular fossæ and base of chest ; cough. (*c*) The lungs and pleura : dyspnœa ; collapse of the lungs ; pleural effusion.

6. Compression of the heart and pericardium. Displacement of the heart ; pericardial effusion ; irregular heart action.

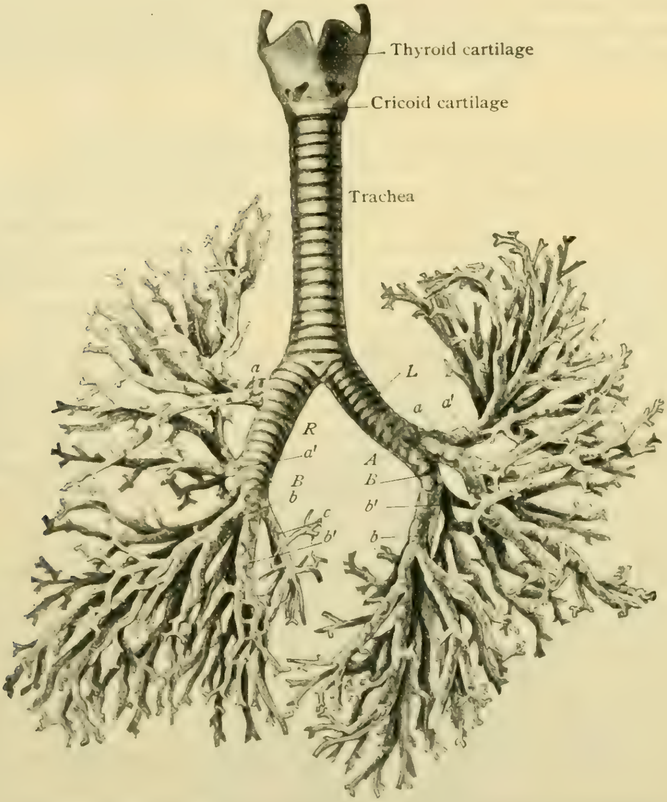
7. Compression of the œsophagus. Dysphagia.

8. Outward pressure upon the walls of the mediastinal space. Widening of intercostal spaces ; bulging of the sternum ; increase of the circumference of the chest on one side ; weakness or absence of vocal fremitus ; increased area of transmission of heart-sounds.

Of course, all of these symptoms are not present in any given case of mediastinal growth, but some of them are sure to be and can be more readily understood if referred to their anatomical causes.

The phenomena referable to the separate subdivisions of the mediastinum can be classified only in a very general way. It may be said, however, that: (1) The anterior mediastinum is the most frequent seat of abscess ; that its growths usually begin in the thymus ; and that the chief symptoms are apt to be those of pressure upon the superior vena cava, invasion of the suprasternal fossa, involvement of the cervical glands, bulging or erosion of the sternum, and dyspnœa. (2) Growths of the posterior and middle mediastinum are apt to originate in the lymph-nodes, and the chief symptoms are those of pressure upon the pneumogastric, recurrent laryngeal or sympathetic nerves, the greater azygos vein, the œsophagus, and the air-passages. The urgent dyspnœa and troublesome cough are out of all proportion to the physical signs (Osler).

Fig. 1558.



Trachea and bronchial tree, anterior aspect. *R*, *L*, right and left bronchus; *A*, left apical bronchus dividing into ventral (*a*) and dorsal (*a'*) branches; *B*, continuation of main bronchus; *b*, *b'*, ventral and dorsal branches; *c*, cardiac bronchus.

THE TRACHEA.

The trachea or windpipe (Fig. 1558) is a tube, composed of cartilage and membrane, extending from the cricoid cartilage to a point opposite the disk below the fourth thoracic vertebra, corresponding to the level of the junction of the first and

second pieces of the sternum, where it divides into the two bronchi. The point of division is usually on the right of the median line: sometimes so far as to lie behind the right edge of the sternum. The trachea is a cylindrical tube, flattened behind. The convexity is due to the so-called rings, which represent only about three quarters of a circle. The length is difficult to determine with accuracy on account of the elasticity of the organ as well as of its variation. It may be said to be, on the average, from 10.5–12 cm. (4–4¾ in.) in man and from 9–11 cm. (3⅔–4½ in.) in woman. The isolated trachea can be stretched and compressed to a surprising extent, and even in life the changes are considerable. The antero-posterior and the transverse diameters are not very different, except just at the lower end, where the trachea enlarges transversely. It is very plausibly stated by Lejars[1] that in life the windpipe is more or less constricted by the tonic contraction of its muscles. According to him, it grows continually smaller from above downward. Braune and Stahel[2] believed that after death it is largest in the middle. We have no doubt whatever that, as a rule, the dead trachea is enlarged transversely at the lower end. Abey[3] gives the following measurements for the upper and lower ends: upper transverse diameter 13.1 mm., sagittal 16 mm.; lower transverse diameter 20.7 mm., sagittal 19.1 mm. The framework of the trachea is so light that its shape may be influenced by neighboring organs, such as the thyroid body and the arch of the aorta.

FIG. 1559.

Transverse section of trachea, showing general arrangement of its wall. × 80.

Structure. — The framework of the anterior and lateral walls of the trachea consists of the so-called *rings* of hyaline cartilage, which form some three-quarters of a circle. In the great majority of cases there are from sixteen to nineteen rings. It is not rare to find twenty, but very rare to find more. The rings are from 2–5 mm. broad, usually measuring 3 or 4 mm. They are plane externally and convex internally, becoming pointed at the ends. They are very irregular in many respects. Sometimes one end bifurcates, the rings above and below ending prematurely. Occasionally bifurcation of the opposite ends of alternate rings is observed. Rarely both ends of the same ring may divide. The first ring, which is broader than the others, is occasionally fused with the cricoid cartilage. A highly elastic fibrous sheath, continuous with the perichondrium of the rings, envelops them, connects their posterior ends, and completes the tube. The distance between the rings is less than their breadth, at times only half as much. Involuntary muscular fibres of the *trachealis muscle* lie between the fibrous sheath and the lining mucous membrane. They are in the main disposed transversely, some of them connecting the ends of the rings; some bundles, however, run longitudinally.

[1] Revue de Chirurgie, 1891.
[2] Archiv f. Anat. u. Phys., Anat. Abth., 1886.
[3] Der Bronchialbaum der Menschen, u. s. w., 1880.

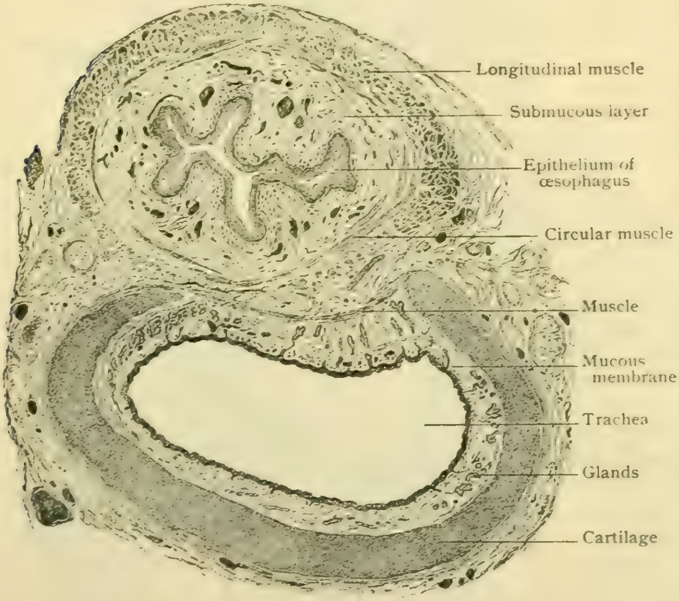
A layer of connective tissue, representing a *submucosa*, separates the cartilage and muscle from the mucous lining of the trachea. The submucosa contains small aggregations of fat-cells and the *tracheal glands*. The latter, tubulo-alveolar mucous in type, are most numerous and largest between the rings of cartilage, especially towards the lower end of the trachea. Over the cartilages they are small and often wanting. Their ducts pierce the mucosa to gain the free surface of the latter.

The *mucous membrane*, smooth and attached with considerable firmness to the underlying tissues, is clothed with stratified ciliated columnar epithelium. Many of the surface cells contain mucus and are of the goblet variety. The stroma of the mucosa is rich in fine elastic fibres, which, in the lower part of the trachea, are condensed into a distinct elastic lamella separating the mucous membrane from the submucosa. Lymphoid cells are constantly found in the mucosa, in places, particularly around the openings of the ducts of the tracheal glands, being aggregated into small collections which suggest lymph-nodules.

Vessels.—The *arteries*, which are insignificant, are branches of the inferior laryngeal from the inferior thyroid, and tend to form a series of horizontal arches between the rings. They anastomose below with the bronchial arteries and with the internal mammaries through the anterior mediastinal twigs. The *veins*, arranged like the arteries, belong to the system of the inferior laryngeals. They communicate with those of the œsophagus, with the thyroid plexus, and, according to Luschka, with the azygos. The *lymphatics*, which are very numerous, are also disposed in horizontal curves. Leaving the windpipe at the sides of the membranous portion, they open into small tracheal lymph-nodes and communicate with the bronchial nodes also.

The **nerves** are from the pneumogastric and sympathetic nerves. Their ultimate distribution, in addition to the supply for the muscular tissue and the walls of the blood-vessels, includes sensory endings within the mucous membrane which, according to Ploschko, are similar to those of the larynx.

FIG. 1560.



Transverse section of trachea and œsophagus of child, seen from below. × 15.

The Relations of the Trachea.—The œsophagus, beginning at the lower border of the cricoid cartilage, lies at first behind the trachea, to which it is connected by areolar tissue; but almost at once it is, relatively to the trachea, displaced to the left, to be pushed over again by the arch of the aorta, where this vessel lies on the left of the trachea. The gullet always lies behind the origin of the left bronchus. Behind the first piece of the sternum the arch of the aorta passes in front of the trachea, which is placed almost symmetrically in the fork made by the innominate and left carotid arteries. The isthmus of the thyroid crosses usually the second and third rings, its lobes resting on the sides of the trachea. The inferior thyroid veins constitute a vascular layer before the lower part of the cervical portion of the trachea. The recurrent laryngeal nerves run up at the back of either side of the

trachea, the left one being the first to reach this position. The inferior laryngeal artery and veins are near them. The relations of the artery and nerve are given with the relations of the thyroid. The remains of the thymus lie in front of the trachea within the thorax. Owing to the forward inclination of the sternum, the trachea is more deeply placed as it descends. A lymph node or, more frequently, a group of them is constantly found under the bifurcation. Tillaux[1] found the distance of the cricoid cartilage above the sternum (in a small series) to range in the male from 4.5–8.5 cm., with an average of 6.5 cm.; and in the female from 5–7.5 cm., with an average of 6.4 cm. This distance, however, may be modified by other factors than the length of the trachea.

Growth and Subsequent Changes.—In the infant the trachea measures from 4–5 cm. in length, begins at a higher point in the neck, as has been shown for the larynx, and divides at a higher point in the thorax. The level of this division varies very much in the fœtus, but at birth is generally opposite the third thoracic vertebra. The lowest position is opposite the fourth and the range extends over two vertebræ.

There are comparatively few records of the changes during childhood.[2] We have found it opposite the lower part of the fourth thoracic vertebra in a child whose age was estimated at about three. Symington[3] has found it at the top of the fifth in two children of six and opposite the fourth in one of thirteen. In the young adult it is opposite the disk between the fourth and fifth thoracic vertebræ, which is its normal position, although it is not abnormal for it to be opposite the fifth. Late in life it descends to the lower border of the fifth and even to the seventh vertebra.[4] The trachea of the infant appears almost round, the rings forming a relatively larger part, perhaps five-sixths of the periphery. According to several authorities, the transverse diameter much exceeds the sagittal; but, although we have seen this condition, we are not inclined to agree that it is normal in the infant, unless, perhaps, at the lower end. The size of the transverse section of the trachea is, for many reasons, hard to determine. Merkel[5] thinks we may accept the following statement of the diameter of the upper part of the trachea without fear of being much out of the way in particular instances: from six to eighteen months, 5 mm.; from two to three years, 6 mm.; from four to five, 7 mm.; from five to ten, 8 mm.; from ten to fifteen, 10–11 mm. *Ossification* of the rings begins decidedly later than in the larynx. The earliest appearances of it observed by Chievitz were at about forty in man and about sixty in woman. His youngest case of complete ossification was at fifty in man and seventy-eight in woman. The deposit is first seen in the upper rings, but not in the first one, the points being irregularly distributed along the borders. They come next in the lower rings, and here at the posterior ends. As the process spreads, there is left a median unossified tract along the trachea, which probably is usually invaded from below.

THE BIFURCATION OF THE TRACHEA AND THE ROOTS OF THE LUNGS.

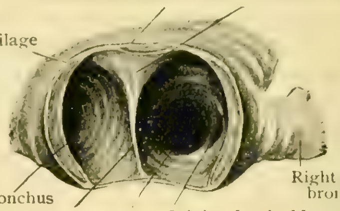
The *carina tracheæ* (Fig. 1561) is a prominent semilunar ridge running antero-posteriorly across the bottom of the trachea between the origin of the two bronchi. It usually starts from a larger anterior triangular space and ends at a smaller posterior one. Heller and v. Schrötter[6] found the framework of the spur cartilaginous in 56 per cent., membranous in 33 per cent., and mixed in 11 per cent. The spur, when cartilaginous, is derived in various ways: from a tracheal ring, from the first ring of either bronchus, or from a combination of these sources. The height of this ridge, especially when membranous, is difficult to measure, but these authors believe that it may reach 6 mm. According to Luschka, the free edge of the spur is 15 mm. from the apparent lowest point of the windpipe, seen from without. This great distance should in part be accounted for by the *interbronchial ligament*, a collection of fibres running transversely in the angle between the bronchi. This band is, however, very variable in development and not constant, so that Luschka's estimate of the distance is probably excessive for most cases. Heller and v. Schrötter found

[1] Anatomie Topographique, 3me édit., 1882.
[2] Dwight: Frozen Sections of a Child, 1881.
[3] Anatomy of the Child, 1887.
[4] Mehnert: Ueber topographische Altersveränderungen des Atmungsapparates, 1901.
[5] Handbuch der Topograph. Anat., Bd. ii., 1899.
[6] Denkschrift der Acad. Vienna, 1897.

the spur on the left of the middle of the trachea in 57 per cent., in the middle in 42 per cent., and on the right of it in the remainder.[1] Semon, in 100 examinations of the living, found it on the left in 59, at the middle in 35, and on the right in 6.

The **roots of the lungs** consist of the bronchi (the right one giving off a branch before entering the lung), the pulmonary artery and vein, the bronchial arteries and veins, the lymphatic vessels and nodes, and the nerves.

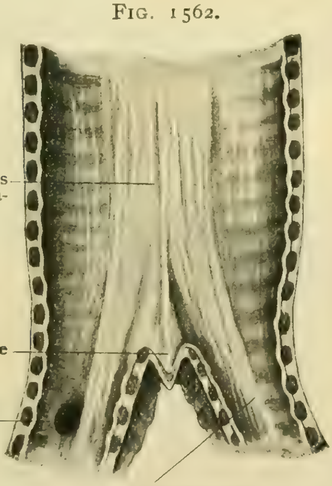
FIG. 1561.



Bifurcation of trachea, seen from above after section of windpipe just above carina.

The **bronchi** (Fig 1562) are the two tubes into which the windpipe divides, one running downward and outward to each lung. Until they enter the lungs, their shape and structure are precisely those of the trachea, the membranous portion being still posterior. This applies also to the branch that springs from the right bronchus before it enters the lung. While treating of the root of the lung we shall consider only the extrapulmonary part of the bronchi. According to modern usage, the term "bronchus" is applied to the whole of the chief tube that runs through each lung; formerly it was restricted to the part from the trachea to the first branch. As the left bronchus gives off no branch before entering the lung, it was described as much longer than the right one. The length of the left bronchus to its first branch is about 5 cm. (2 in.), that of the right is rarely more, and often less, than 2 cm. (¾ in.). There are some eight or ten rings in the left bronchus before the branch, while in the right one there are three, often two, and sometimes four. The right bronchus, which is the more direct continuation of the trachea, is the larger. The diameter of the bronchi at their origin is greater from above downward than from before backward. The dimensions are very differently given. According to Aeby, the transverse diameter of the right bronchus is from 13.5–21 mm. and that of the left from 12.5–17 mm. Braune and Stahel found that the calibre of the right one is to that of the left as 100 : 77.9. The extreme ratios of the series were 100 : 71.6 and 100 : 83.3. We have deduced from Heller and v. Schrötter's tables that in some 10 per cent. the calibres are equal. It was formerly taught that the larger right bronchus is more nearly horizontal than the left, but that the contrary is true is easily proved by a glance down the trachea in a frozen section (Fig. 1561). The cause of the error is that, if it be not recognized that after the apparent splitting of the right bronchus the lower division is the main trunk, the eye is apt to follow the upper border of the primitive bronchus, which carries it along the upper branch. It is very difficult to determine the angles at the origin of the bronchi, for the parts are so flexible that observations on non-hardened subjects are of little value, and it is not easy accurately to measure even good preparations, on account of the irregularity of the outline. One fact which adds to the difficulty of taking satisfactory measurements, and which also tends to make the right bronchus the more direct continuation of the trachea, is the inclination of the latter to the right as it descends.

FIG. 1562.



Bifurcation of trachea laid open after incision along anterior wall of trachea and bronchi.

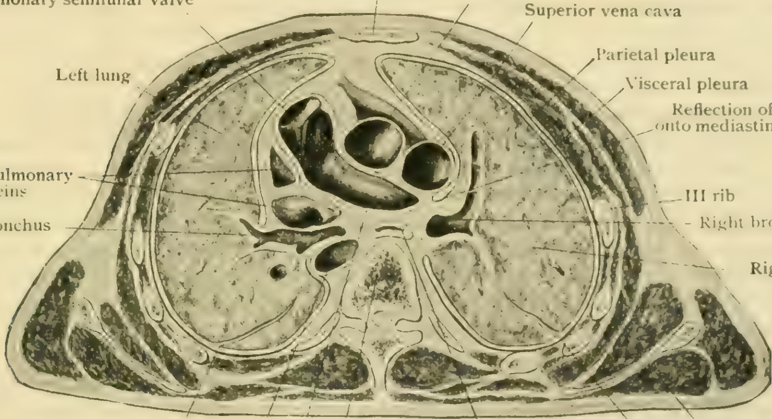
[1] They state that this remainder consists of 8 cases, but as their series comprised 125, it would seem that there must be a misprint.

We have made measurements on two casts from frozen sections of the adult, and one from a section of a child thought to be of about three years, and have calculated the angles between the prolongation of the axis of the terminal part of the windpipe and that of each bronchus. An attempt was also made to measure the angles from a skiagraph made by Blake[1] after injecting fusible metal into the trachea of a hardened body. Two observations on adults by Kobler and v. Hovorka[2] are included for comparison.

It seems that the *subtracheal angle*, that of divergence of the bronchi, is about 70°. We have found it precisely that in another specimen. Kobler and v. Hovorka measured the lateral angles in the hardened bodies of sixteen new-born infants. The average was right 25.6, left 48.9. The variations ranged on the right from 10 to 35 and on the left from 30 to 65. We found their average angle of divergence 74.5. This shows that, contrary to the general impression, the bronchi are not more nearly vertical in the infant than subsequently. Aeby gives the angles of divergence of two new-born children as 33 and 61; Mettenheimer[3] as 50 and 63.

Vessels.—The *pulmonary artery* at its bifurcation is anterior to the bronchi and at a lower plane. Each branch of the artery rises over the bronchus and comes to lie more or less external to it. This apparent crossing of the bronchus by the artery occurs on the right just after the origin of the first secondary bronchus. The usual teaching, following Aeby, that the artery actually arches over the extrapul-

FIG. 1563.



Transverse section of thorax at level of fifth thoracic vertebra.

monary bronchus and lies behind it, is incorrect. The artery divides before entering the lung, one branch entering through the upper and the other through the lower part of the hilum.

The *pulmonary veins* are usually two on each side. The superior lie in front of and below the artery. The inferior are the lowest of the large vessels of the lung-root, passing from behind under the bronchus into the heart.

The *bronchial arteries* follow the bronchi along their posterior surfaces. The *bronchial veins* are both anterior and posterior. On the right side both open into the larger azygos vein. The left posterior ones often receive the anterior and open into the superior hemiazygos. There may be various anastomoses with mediastinal, pericardial, and tracheal veins.

The *lymphatics* run for the most part behind the bronchi. The lymph-nodes are for the most part on the posterior and inferior aspects of the tubes, the group under the bifurcation joining others at the sides. Some nodes occur on the front.

The **nerves** from the sympathetic and vagus form plexuses both before and behind the bronchi.

[1] American Journal of the Medical Sciences, 1899.
[2] Sitzbericht. Acad., Vienna, 1893.
[3] Morpholog. Arbeit. Schwalbe, 1894.

The **dimensions** of the lung-roots are difficult to determine. They are narrower below than above and shorter behind than in front. The lower posterior borders, which are formed by the inferior pulmonary veins, are of about the same length (2 cm.) on each side and very symmetrical. We may put the right root in front and above at from 4–4.5 cm. and the left at about 1 cm. longer. They are thickest above, and expand as they approach the hilum of the lung, where the diameter is approximately 3.5 cm., the left one being rather the thicker. The height at the hilum is from 5–6 cm., probably sometimes rather more.

The Relations of the Roots.—Below lies the pericardium covering the heart, chiefly the left auricle. The great azygos vein arches over the right root from behind, to join the superior vena cava, which is against the root in front. The arch of the aorta crosses the left root from before backward, being less closely applied to it behind than elsewhere. The œsophagus is behind the very beginning of the left root. The pleura is reflected over each root, which it completely envelops as it passes from the parietal into the visceral layer. The broad ligament of the lungs is a fold of pleura extending downward from the end of the root. The phrenic nerve of each side passes in front of the root, between the pericardium and the pleura.

PRACTICAL CONSIDERATIONS : THE AIR-PASSAGES.

The Trachea and Bronchi.—The elasticity and mobility of the trachea, the compressible character of its walls, the loose cellular tissue in which it lies, and the variety of the structures with which it is in close relation should all be remembered in considering its injuries and diseases.

Wounds of the cervical portion of the trachea—as in cut throat below the cricoid—are not rare. The trachea is rendered more superficial by extreme extension of the neck, and is also elongated. A deep wound may therefore sever it completely, in which case the lower end may retract below the level of the superficial wound, making the hurried introduction of a tracheotomy tube difficult.

Rupture—"fracture"—of the cervical trachea has resulted from contusion, and in the presence of pre-existing disease has followed coughing. The depth of the thoracic trachea protects it from all but penetrating wounds, and these, on account of the important structures also implicated, are usually fatal.

Disease beginning in or confined to the trachea is rare, but it may be involved in the extension of either bronchial or laryngeal morbid processes. The normal tracheal mucous membrane is said to resist cadaveric disintegration longer than any other mucous membrane of the body (Elsberg).

Stenosis of the trachea, if from intrinsic change, is usually due to ulceration, either syphilitic or tuberculous, followed by cicatrization. It is, however, far more commonly due to extrinsic causes, the mechanism of which will be readily understood if the relations of the trachea are recalled (page 1836). From above downward it is evident that the trachea may be compressed by enlargements of the thyroid gland, by retro-œsophageal tumors or abscesses, by carotid, innominate, or aortic aneurism, or by lymphatic swellings in the neck or near the bifurcation. As the posterior part of the tracheal wall is musculo-membranous (partly in order to avoid undue pressure of the trachea on the œsophagus), the impaction of a foreign body in the latter tube may cause tracheal narrowing. The trachea may be involved in disease originating elsewhere, as in tuberculous infection of the thoracic lymphatic glands, or in carcinoma of the same glands, or of the cervical chain, or of the œsophagus. Abscesses or aneurisms may ulcerate through its walls and empty into its lumen, suffocating the patient. The close relation of the trachea to the aorta makes it possible in some cases of aortic aneurism to hear a systolic bruit either in the trachea or at the patient's mouth when opened. This is either the sound conveyed from the sac or is produced by the air as it is driven out of the trachea during the systole (Osler). The sign known as "tracheal tugging" also depends upon the same close relation. With the patient erect, his mouth closed and his chin elevated, when the cricoid is grasped between the finger and thumb and pressed gently and steadily upward, if aortic aneurism or dilatation exists, the pulsation of the aorta will be distinctly transmitted through the trachea to the hand (Oliver).

Tracheotomy may be required for obstruction in the larynx or above it, for the removal of foreign bodies, or as a preliminary step in other operations, as excision of the tongue.

It may be done at any point between the cricoid cartilage and a short distance above the suprasternal notch. The difficulties of the operation increase with the distance from the cricoid because (*a*) the depth of the trachea from the surface increases as it approaches the thorax; (*b*) it is more movable; (*c*) it is more completely covered in by the sterno-hyoid and sterno-thyroid muscles; (*d*) it is more apt to be overlapped by the common carotids; or (*e*) crossed by the left common carotid when it arises from the innominate artery; or by (*f*) various venous trunks, as the transverse branches between the anterior jugulars, or the inferior thyroids, or even by the left innominate vein, which,—lying as it does in front of the trachea,—in the presence of venous congestion, may extend above the level of the top of the sternum. Moreover, in children under two years of age the upper edge of the vascular thymus gland may lie in front of the trachea at the root of the neck. The innominate artery itself or the thyroidea ima may occupy the same position.

For these reasons tracheotomy is done with comparative rarity below the level of the isthmus, which lies in front of the second, third, and fourth tracheal cartilages. The incision is made with the head in full extension so as to lengthen the trachea, steady it by increasing its tension, and bring it nearer the surface. The chin, thyroid angle, and suprasternal notch should be in the same line. The incision should be exactly in this line, extend about two inches downward from the cricoid, and divide the skin, platysma, and fascia and expose the interval between the sterno-hyoid and sterno-thyroid muscles, which may be separated by blunt dissection. The pretracheal fascia is then divided, exposing the upper ring of the trachea and the thyroid isthmus. The isthmus may be depressed to give more room for the tracheal opening, or may, after ligation on both sides, be divided in the mid-line, where, as Treves says, it, like other median raphes, has but slight vascularity. A large communicating branch between the superior thyroid veins often runs along the upper border of the isthmus, and over its anterior surface there may be a plexus made up by the branches of the thyroid veins of the two sides. These vessels, if present, may be dealt with separately or may be picked up with the two sides of the divided isthmus in the grasp of heavy hæmostatic forceps, which by dropping over the neck raise the trachea into the wound (Pearce Gould).

The trachea is then seen and felt, steadied and made still more superficial by upward traction by a small, sharp hook thrust into the lower edge of the cricoid, and opened exactly in the middle line by a bistoury thrust in at about the level of the third or fourth ring and made to cut upward to about the first.

In very fat or very muscular persons the depth of the trachea is increased.

In children its small size, its shortness (one and a half inches in the neck in a child of from three to four years of age), its mobility, its depth (on account of the considerable quantity of subcutaneous fat usually present), the compressibility of its thin cartilaginous rings, the height to which the great vessels may rise in front of it, the venous engorgement usually present, and the occasional interposition of the thymus (*vide supra*), all increase the difficulties of the operation.

Foreign bodies in the air-passages are most likely to be arrested at the upper laryngeal opening, at the ventricle or the glottis, at the bifurcation of the trachea, or in the right bronchus. They are apt to enter that bronchus instead of the left because (*a*) the right lung is larger (the left being encroached upon by the heart) and there is a greater intake of air and a stronger current; (*b*) the right bronchus has the larger transverse diameter; (*c*) it is less horizontal and therefore more directly a continuation of the trachea than the left bronchus (page 1838); and (*d*) the carina tracheæ is situated to the left of the middle line in the majority of cases (page 1837). If small enough, they may be drawn into some of the lesser bronchioles by the inspiration—usually sudden—which has caused their entrance into the air-passages. The immediate symptoms are always those due to obstruction of the air-current, either mechanical—from the size of the foreign body—or reflex, as when spasm of the glottis is excited by the irritation of the superior laryngeal or tracheal nerves.

The symptoms that would suggest arrest in the larynx are violent cough, alteration or loss of voice, frequent spasm, stridor, and rapidly increasing dyspnœa (from swelling and œdema of the mucosa). In the trachea a foreign body is apt to cause moderate but persistent cough, hurried respiration, occasional reflex spasm of the glottis, and slight dyspnœa. Arrest in a division or subdivision of a bronchus, if the body is large enough to plug it, will cause absence of vocal and respiratory sounds over the area involved, collapse of the lung, and flattening of the side of the thorax. Later symptoms will be due to irritation (hyperæmia and catarrh), followed by infection (inflammation and ulceration) and, in cases of long standing, possibly by the involvement of neighboring structures or organs (the lungs or pleura, the aorta or vena cava, the pericardium, or the œsophagus). The relatively unyielding walls of the air-passages render this termination less common than in cases of œsophageal impaction of foreign bodies. Spontaneous expulsion during a coughing spell may take place, or operation may be needed. (See thyrotomy, laryngotomy, tracheotomy, bronchotomy.)

The *bronchi* begin at the bifurcation of the trachea, about opposite the space between the fourth and fifth thoracic vertebræ. This is behind the lower part of the arch of the aorta and on a horizontal line passing through the sternal angle (angulus Ludovici) and the root of the spine of the scapula. As at their origin they are nearer the posterior than the anterior wall of the thorax, auscultatory sounds in the primary bronchi can best be heard between the scapulæ and about the level of the inner ends of their spines.

The most frequent as well as the most serious forms of compression of the air-passages are found within the thorax. In the neck, even in the presence of large tumors or swellings, the feeble resistance of the skin and other tissues may permit the trachea to escape; but within the thorax, between the spine and the unyielding sternum, even small growths may cause serious symptoms of obstruction.

Thus the group of lymph-nodules surrounding the bifurcation may, when diseased, make pressure upon either the trachea or bronchi, as may aneurisms of the aorta or innominate, or tumors of the posterior mediastinum, or even a dilated left auricle.

In chronic interstitial pneumonia attended by great increase in the connective-tissue elements of the lung, followed, as is invariably the case, by contraction of such tissue, the atmospheric pressure retains the lung in contact with the inner surface of the chest in spite of the pull of the atrophying fibrous tissue. The force is, therefore, exerted on the bronchi, the walls of which are dragged apart, forming great cavities (*bronchiectasis*). Such cavities may also be due to dilatation under increased pressure from within, as when a foreign body or an aneurism occludes one bronchus; or to chronic disease and weakening of the bronchial walls.

Asthma of the spasmodic type may be due to reflex pneumogastric irritation causing contraction of the muscular tissue in the walls of the smaller bronchi. It should be noted that the transverse muscular fibres (trachealis muscle) connecting the ends of the tracheal cartilages have in the bronchioles become converted into a complete circular muscular coat, and are found even in divisions so small that the cartilage has disappeared.

Bronchotomy.—The relations of the bronchi (page 1857) show that in case of impaction of a foreign body in or just below a primary bronchus it might be reached by a posterior thoracotomy done at the level of the fourth to the sixth or seventh rib. The flap of soft parts is three inches square, its base being about over the costo-vertebral gutter on the side to be operated upon. The underlying ribs are separated from the pleura and divided. The proximity of the great azygos vein on the right side, and of the arch of the aorta, the descending aorta, the œsophagus, and the left auricle on the left, must be remembered. It is more difficult to retract the pleura on the right side so as to expose the bronchus. Bryant has called attention to the following anatomical points bearing upon this operation, whether it is undertaken for the removal of a foreign body from a bronchus or the œsophagus, or for posterior mediastinal tumors or abscess, or for the relief of pressure from enlarged bronchial glands: the lower portion of the fourth dorsal vertebra is the boundary line between the posterior mediastinum and the lower part of the superior medias-

tinum ; the spinous process of any dorsal vertebra, with the exception of the first, eleventh, and twelfth, denotes the situation of the posterior extremity of the rib articulating with the transverse process of the vertebra immediately below ; the tips of the spinous processes of the first, eleventh, and twelfth dorsal vertebræ are above rather than opposite the transverse processes of the vertebræ immediately below ; the space between the ends of the transverse processes and the angles of the ribs varies from one to two and a half inches, according to the numerical position of the rib ; the incomplete rings of the bronchi render those tubes easily recognizable by touch ; they are found about an inch and a half anterior to the opening in the thoracic wall.

THE LUNGS.

The lungs are a pair of conical organs, each enveloped in a serous membrane,—the pleura,—occupying the greater part of the cavity of the thorax, and separated from each other by the contents of the mediastina. Although in general conical, the lung differs in many respects from a true cone. The base is concave, moulded over the convexity of the diaphragm, and descends farther at the back and side than at the front and mesially. The apex is not over the middle of the base, but much to the inner and posterior side of it, so that the back and inner side of the lung descend much more directly than the rest. The right lung is the larger on account of the greater encroachment of the heart on the left.

The **surfaces** of the lungs are the *base*, the *external surface* (which is the mantle of the cone from apex to base, and embraces all the periphery from the front of the mediastinal space around the wall of the thorax to nearly opposite the front of the vertebral column), and the *mesial* or *mediastinal surface*.

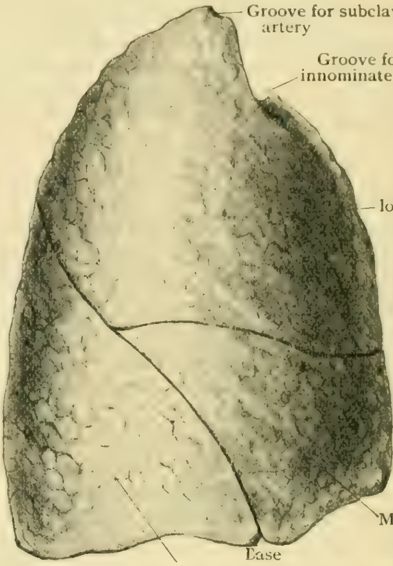
The **borders** are the *inferior*, which surrounds the base, and the *anterior* and *posterior*, which bound respectively the back and front of the internal surface.

The **external surface** (facies costalis), much the largest, is closely applied to the portion of the wall of the pleural cavity formed by the ribs and the intercostal muscles. The region of the apex is a part of this surface. It rises slightly—possibly 1 cm.—above the oblique plane of the first rib, which indents it towards the front. The apex itself is in the internal and posterior part of this region. It rests closely against the firm fibrous structures that roof in this region, and is grooved transversely by the subclavian artery, more anteriorly on the right lung than on the left. A slight groove made by the subclavian vein may be found in front of the arterial one. The rest of the external surface is smooth, except where it may be slightly depressed beneath the individual ribs. It should be noted that a part of what is termed the external surface faces inward against the vertebral column and the first part of the ribs as they pass backward. The external surface descends lowest at the back and at the side.

The **mesial surface** (facies mediastinalis) is approximately plane, except for the *cardiac fossa*, which is much deeper on the left than on the right, and extends as far as the lower surface. The left lung presents a shelf-like projection from behind under this fossa. The other chief feature of the internal surface is the *hilum* for the entrance of the structures composing the root of the lung. It is situated nearer the back than the front and below the middle, being behind and above the cardiac fossa. The outline of the hilum in the left lung is approximately oval, with the lower end sharpened and the long diameter vertical. It is more triangular in the left lung, as the root expands forward near the top. The position of the bronchi and the chief vessels as they enter the lungs differs on the two sides. *Right lung :* the chief bronchus enters at the middle or lower part and its first branch near the top, both being at the back of the hilum ; the pulmonary artery, generally in two branches, enters one branch in front of the main bronchus and the other in front of the secondary bronchus, but at a higher level ; the superior pulmonary vein is high and in front of the higher arterial branch ; the inferior, often subdivided, is near the lower end of the hilum ; one branch may be in front of the bronchus and one below it. *Left lung :* the bronchus enters the back of the hilum rather above the middle ; the pulmonary artery is at the top, sometimes in two divisions ; the superior pulmonary vein is high up in front,

causing the expansion which makes the outline triangular, the inferior vein being in the lower angle. The inner surfaces are also marked by certain adjacent structures which require a separate account for each lung. The *right lung* presents a vertical groove above and in front for the superior vena cava, and one for the vena azygos major, which is distinct behind the upper part of the hilum and above it where this vein runs forward to the cava. The right subclavian artery, owing to its high origin from the innominate, indents but little of the internal surface. A more or less marked vertical groove for the œsophagus is seen behind the hilum and below that for the azygos. There is also a groove below on the inner surface where the inferior vena cava turns forward to enter the heart. A slight impression made by the trachea may also be present near the apex. The inner surface of the *left lung* is deeply grooved by the aorta arching over the root and descending behind it, the imprint growing faint and disappearing at the lower end. The left carotid and subclavian arteries make distinct impressions at the upper part diverging from the aortic groove.

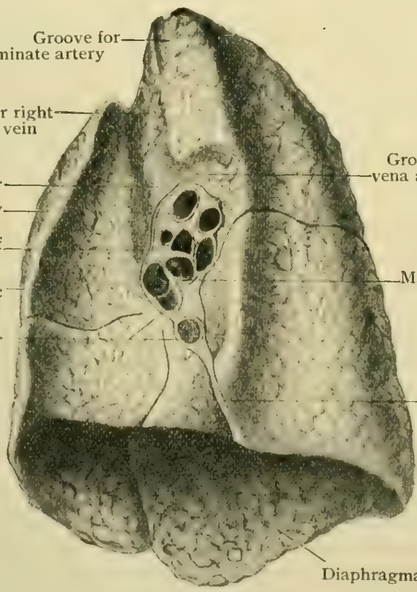
Fig. 1564.



Right lung, hardened *in situ*; antero-lateral aspect.

The **base** (facies diaphragmatica) is concave, that of the right one being rather the more so. Both are semilunar in outline, owing to the part cut out of them by the heart; since this encroachment is greater on the left, the base of that lung is a narrower crescent.

Fig. 1565.

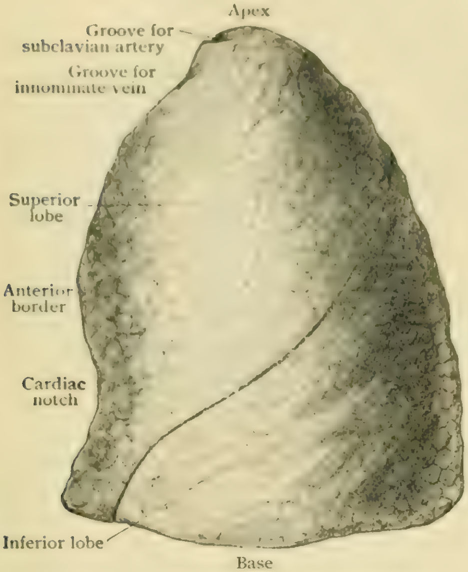


Preceding lung; median aspect.

The **inferior border** surrounds the base. The latter forms about a right angle with the internal surface, but at the periphery, especially at the back and at the side, a sharp edge of lung is prolonged down into the narrow space between the diaphragm and the thoracic walls. The **anterior border** is sharp and somewhat irregular, often presenting a series of convexities. Starting near the apex, it descends on both lungs with a forward curve, which is most prominent in the upper part, so that the lungs nearly or quite meet behind the manubrium. The anterior border of the right lung then inclines downward and outward so as to meet the inferior border in a gradual curve. On the left this convexity is changed into a sharp concavity where the border curves outward around the

heart. As this concavity ends in front, the anterior and inferior borders enclose a prolongation of the lung towards the median line, known as the *lingula*. The **posterior border** is variously described. Often the term is applied to the thick mass of lung that fills the region of the thorax along the sides of the vertebræ and the part of the ribs running backward. Properly, it is a ridge starting on the inner side of the apex, growing sharp as it descends, but becoming vague and effaced at the lower end. The position of this line is not the same on both sides, nor is it probably always dependent on the same causes. On the *left* it is more regular, beginning as the posterior border of the groove for the subclavian artery, and continuing as that of the aortic impression until it is lost near the lower border of the lung. Sometimes the beginning has no relation to the subclavian groove, but appears posterior to it, the lung-tissue forming a ridge which enters a little into the space between the front of the spine and the œsophagus, which is here deflected to the left. The line behind the aortic groove lies on the side of the vertebræ, and consequently is the farther back the more the aorta is on the side of the column. On the *right* the posterior border is farther forward, being about opposite the anterior surface of the spine. It may begin as the posterior border of the subclavian groove, or more posteriorly, and continues as a ridge tending to insinuate itself between the spine and the contents of the posterior mediastinum. From just above the root of the lung it is for a short distance continued as the back of the groove for the major azygos vein, below which it tends to pass between the œsophagus and the pericardium, and finally disappears a little above the lower border.

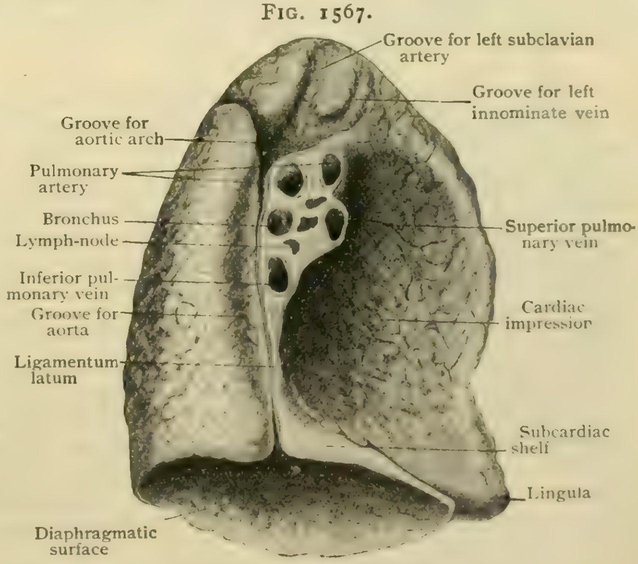
FIG. 1566.



Left lung, hardened *in situ*; antero-lateral aspect.

The Lobes and Fissures.—The lungs are divided into lobes by deep fissures. The *chief fissure* starts on the inner aspect of the lung, behind the upper part of the hilum, and ascends to the posterior surface, which it may reach at the same level on both sides, or, as is perhaps more frequent, the right fissure may be one intercostal space lower. The fissure then descends obliquely along the outer aspect of the lung, and reaches the inferior border, where it ends somewhat sooner on the right side than on the left. In the right lung this occurs at the front of the lateral aspect, while it is likely to

FIG. 1567.



Preceding lung; median aspect.

encroach somewhat anteriorly in the left, terminating below the lingula. The left lung is thus divided into a *superior* and an *inferior lobe*. In the right lung a *middle lobe* is cut off from the superior by a *secondary fissure*, which starts from the main fissure far back on the lateral aspect and runs forward, either straight or with an upward or a downward inclination. The foregoing description applies to the course of these fissures as seen on the surface; but the chief fissure is, moreover, very deep, penetrating to the main bronchus, and completely dividing the lung into a part above it and one below it. The depth from the surface of an inflated lung to the bronchus at the bottom of the fissure (taken at the point of origin of the secondary fissure on the right and at a corresponding point on the left) is from 7–8 cm. on the right and about 1 cm. less on the left. The secondary fissure is much less deep and may end prematurely, or even be wanting, so that the middle lobe is a very irregular structure. The *left superior lobe* comprises the apex and the entire front of the lung, while the inferior takes in most of the back and all of the base, unless the lingula be regarded as constituting its anterior border. In the right lung the middle lobe forms a varying part of the front and one-fourth or one-third of the base. The volume of the upper and lower lobes of the left lung is about equal. In the right lung that of the inferior is about equal to that of the other two. We consider the middle lobe simply as a piece cut off from the upper, so that the right upper and middle lobes correspond to the left upper one.

Variations of the Lobes and Fissures.—Were it not for the great difficulty in properly examining the lungs, their marked tendency to variation would doubtless be more fully appreciated. Schaffner[1] has shown that an *accessory inferior lobe* is very frequently found on the under surface, extending up onto the inner surface in front of the broad ligament. This lobe may be merely indicated by shallow fissures or sharply cut off from the rest. It may present a tongue-like projection inward or may comprise the entire inner portion of the base. It usually represents, when present, from one-fifth to one-third of the base. It may occur on either side or on both, but is larger and more frequently well defined on the right. On the other hand, it is present, or at least indicated, rather more often on the left. Schaffner found it in 47.1 per cent. of 210 lungs. The lobe of the right lung represents the *subcardiac* lobe of many mammals, that of the left being evidently its fellow. The irregularity and occasional absence of the fissure marking off the middle lobe have been mentioned. An irregular fissure may subdivide the left lung into three lobes, and both lungs may exceptionally be still further subdivided, especially the right one. A little process of the right lung just above the base, behind the termination of the inferior vena cava, may very rarely become more or less isolated as the *lobus cavæ*. The azygos major vein may be displaced outward, so that, instead of curving over the root of the lung, it may make a deep fissure in the upper part of the right lung, marking off an extra lobe.

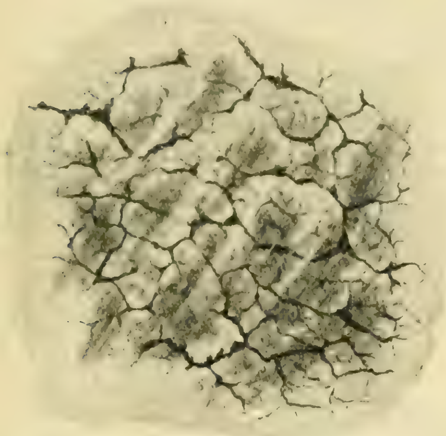
External Appearance and Physical Characteristics.—The adult lung is bluish gray, more or less mottled with black. At birth the lung-tissue proper is nearly white, but the blood gives it a pinkish or even a red color. It grows darker with age, partly, perhaps chiefly, by the absorption of dirt, but also by the greater quantity of pigment. Before middle age the lungs become decidedly dark by the presence of black substance (be it dirt or pigment), arranged so as to bound irregular polygons from 1–2.5 cm. in diameter, which are the lobules. At first, while the black is scanty, the lines seem to enclose considerably larger spaces, but when more of the lobules appear, owing to a greater deposit of the pigment in the areolar tissue and lymphatics marking them off, it is clear that their diameter rarely much exceeds 1.5 cm. Some, however, are relatively long and narrow. It is remarkable that the deposit of pigment is much greater in certain places than in others. Thus the rounded posterior parts of the lungs are darker than the anterior portions. In general the external surface is much darker than the mediastinal or the base, while the surface within the fissures is the lightest of all. Moreover, the pigment on the external surface, before the coloration has become general, is often in stripes corresponding to the intercostal spaces, as if there were more pigment in the places most accessible to light.

The lungs being filled with air, after respiration has begun, are soft and crackling on pressure. They are extremely elastic, so as to collapse to perhaps a third of their size when the chest is opened.

[1] Virchow's Archiv, Bd. clii., 1898.

The **weight** of the lung is difficult to determine, owing to the impossibility of quite excluding fluids. Sappey puts it at 60 or 65 gm. for the fœtus at term, and at 94 gm. on the average for the new-born infant that has breathed (thus showing convincingly the worthlessness of the method). Krause gives the adult weight as 1300 gm. in the male and 1023 gm. in the female. According to Braune and Stahel, the weight of the right lung is to that of the left as 100 : 85.

FIG. 1568.



External surface of lung, showing polygonal areas corresponding to lobules mapped out by deposits of pigmented particles within connective tissue.

The **specific gravity** of the lung before breathing is greater than that of water, so that the lung sinks in it. Wilmart[1] has recently stated it as 1068, which is the same as Sappey's statement and greater than that of Krause (1045–1056). After breathing it may be as little as 342, but may go as high as 746. Probably figures like the latter represent either diseased or congested lungs.

The **dimensions** are necessarily of little value. According to Krause, the length in man is 27.1 cm. on the right and 29.8 cm. on the left. In woman these dimensions are 21.6 cm. and 23 cm. respectively. There is little difference in length between the lungs, but such as there may be is in favor of the left. The other dimensions are probably more variable. According to Sappey, the antero-posterior diameter, which increases from above downward, finally reaches 16 or 17 cm. Krause gives the transverse diameter at the base in man as 13.5 cm. on the right and 12.9 cm. on the left, and in woman as 12.2 cm. and 10.8 cm. respectively.

The average **capacity** of the lungs of a powerful man, after an ordinary inspiration, is stated at from 3400–3700 cc. The vital capacity, which is the greatest amount of air that can be expelled in life after a forced inspiration, is from 3200–3700 cc. for men and 2500 cc. for women.

The Bronchial Tree.—The plan of the bronchi of the human lung (Fig. 1558) is as follows. The two *primary bronchi*, resulting from the bifurcation of the trachea, run downward and outward into the lowest lateral part of the lungs, the right one descending more steeply. Their course has been variously described. That of the right one has been said to resemble a C with the concavity inward, and that of the left an S; but both comparisons are very forced. On their way they give off *secondary bronchi*, which are divided into *ventral* and *dorsal* branches. The *ventral* might more properly be called lateral, since they spring from the outer aspect of the primary bronchus. They are much the larger, and supply all the lung, except the apex and the posterior portion lying along the spine ; the latter is supplied by the

FIG. 1569.

Relations of bronchial tree to anterior thoracic wall, as shown by X-rays. (*After Blake.*)

[1] La Clinique, 1897.

dorsal branches, which are small and irregular. There are usually four large and well-marked ventral secondary bronchi, besides one or two insignificant ones the nature of which is not easily determined. The ventral bronchi describe a spiral course through the lung, curving forward and inward as they descend, so as to be in the main parallel with the chief fissure. The *dorsal* branches, running backward, inward, and downward, are not more than four in number, and may be reduced to two. There are two bronchial tubes besides those mentioned above: one, the *apical bronchus*, supplies the upper part of the lung, on the right springing from the primary bronchus 2 cm. or less from its origin. It is a large branch, about 10 mm. in diameter, running upward and outward, and divides into three branches, one of which ascends and two of which run downward and outward on the front and back respectively. It is really the first dorsal branch of the right primary bronchus, but we have not included it in the dorsal branches. On the left the apical bronchus, which closely resembles the right one, but is rather smaller, rises from the first ventral bronchus, of which it may be called a dorsal branch. The other secondary bronchus, not included in the foregoing scheme, is the *subcardiac bronchus*, which on the right arises usually from the main trunk between the first and second ventral bronchi, or from the second ventral bronchus. It runs downward and inward to the region in front of the hilum and above the lower border of the lung, which may be marked off as a separate lobe, held to represent the cardiac lobe of mammals. On the left the corresponding bronchus arises always from the second ventral branch.

FIG. 1570.

Relations of bronchial tree to posterior thoracic wall, as shown by X-rays. (*After Blake.*)

Homologies of the Bronchi.—We are indebted to Aeby[1] for the idea, now practically universally accepted, that there is a main or primary bronchus extending through the lung and giving off both ventral and dorsal branches. After the bifurcation of the pulmonary artery, each of its subdivisions reaches the front of the primary bronchus of each lung, and (according to Aeby) crosses over it so as to lie behind it. This alleged crossing occurs on the right just after the origin of the apical bronchus, which is said, therefore, to be above the crossing, and is called by Aeby the *eparterial bronchus*. Thus on the right all but one of the branches, and on the left all, without exception, are given off below the crossing, and are called *hyparterial bronchi*. Aeby attached so much importance to this relation that he considered the little irregular middle lobe of the right lung, because it is supplied by the first hyparterial bronchus, the representative of the left upper lobe, the right upper lobe being without a mate and the two lower lobes homologous. It is difficult to understand why such a relation should be of so great import. Narath,[2] in refutation of Aeby, pointed out that during fœtal life the pulmonary artery is a very insignificant, and withal variable structure, and, moreover, that it does not cross fairly over the main bronchus, but runs on its outer side, the crossing occurring, if at all, deep in the lung. Narath showed also that the so-called eparterial apical bronchus of the right lung is present in the left, arising from the first ventral instead of the primary bronchus. It is a tertiary bronchus from the first ventral which, especially on the right, is (among mammals) given to wandering, so that it may spring from the main bronchus or even from the trachea. The arterial relation he considers of no importance. Huntington,[3] after much work on human and mammalian lungs, came to somewhat similar conclusions. He believes that the primary type among mammals is one with a hyparterial bronchus on both sides, and the furthest

[1] Der Bronchialbaum der Säugethiere und des Menschen, 1880.
[2] Verhandl. d. Anat. Gesellschaft, 1892.
[3] Annals of the New York Academy of Sciences, 1898.

departure from it one with symmetrical eparterial bronchi. The type found in man is the most common among mammals. Huntington would do away entirely with the terms "eparterial" and "hyparterial," except for purposes of topography. Certainly there is no need of them in human anatomy as a special study; whether or not the arterial relations should, as Narath maintains, be absolutely discarded in comparative anatomy, we must leave undetermined.[1]

It must be admitted that were our knowledge derived solely from the human lung it would be impossible to make out this plan. We shall now describe what is actually to be seen.

Distribution of the Bronchi.—In the *right lung* the apical bronchus, with a diameter of about 10 mm., arises about 2 cm. from the trachea (often nearer and rarely farther), and, entering the top of the hilum, divides as described above. The diameter of the main trunk, after giving off the apical branch, is 12 mm. The first right ventral branch arises from its outer side, about 5 or 6 cm. from the bifurcation of the trachea, and runs downward, outward, and forward. It is about 8 mm. in diameter. The apical branch and the first ventral supply the superior lobe, of which the middle lobe is really a part. Shortly after the origin of the first ventral branch the chief bronchus seems to break up into a bundle of branches running mostly in the same general direction, but diverging. It is usually not possible to determine which is the main trunk, but the subcardiac branch may sometimes be distinguished. In the *left lung* the first branch is the first ventral, with a diameter of 12 mm., arising some 40 mm. from the bifurcation. It gives off the apical, 7 or 8 mm. in diameter, after which the diameter of the main branch is 12 mm. It presently breaks up like the right one. On this side the first ventral supplies the upper lobe. A branch from the second ventral goes to the accessory lobe, if there be one. The branches of the left bronchus are very apt to give the appearance of being divided into an upper and a lower set, the former, consisting of the first ventral branch, bearing the apical and supplying the superior lobe, while the lower sheaf of branches supplies the inferior.

The secondary bronchi give off branches of 4 or 5 mm. in diameter, which diverge at acute angles from the parent trunk, and in turn give off smaller branches at continually greater angles. The branches to the lobules are probably the fourth or fifth branches. They are about 1 mm. in diameter and arise by the subdivision of the preceding branch. In the larger tubes the ramification is clearly from the side, but in the smaller ones it is more suggestive of a splitting. His,[2] Minot,[3] and more recently Justesen[4] defend the theory that the origin of the bronchi is throughout by bifurcation, with subsequent unequal growth of the subdivisions until we come to the smallest. Aeby gives the following table of diameters of the main bronchus above the origin of the chief branches, the nomenclature being his.

	Right.	Left.
Above the eparterial branch	12.8 mm.	. . .
Above the first hyparterial branch	9.6 mm.	10.1 mm.
Above the second hyparterial branch	7.2 mm.	7.7 mm.
Above the third hyparterial branch	5.8 mm.	6.4 mm.
Above the fourth hyparterial branch	4.6 mm.	5.3 mm.

The **variations of the bronchial tree** are very numerous. Very rarely indeed the right apical branch does not spring from the primary bronchus, so that the disposition of the two sides is symmetrical. The origin of the left apical from the primary bronchus has been observed in two or three cases of infants, which also makes the arrangement symmetrical. Chiari[5] has seen several cases in which the right apical bronchus is double, the duplication being apparently due to the springing of one of its branches from the main bronchus. The right apical bronchus may spring from the trachea, as in the sheep and other mammals. We have such an instance in which it is separated from the chief bronchus by the azygos vein. The dorsal secondary bronchi are particularly likely to be reduced in number. The ventral ones may also be reduced by two having a common origin or by one becoming merely the branch of another. The number may be apparently increased by the separate origin from the parent stem of what are normally branches of branches.

The Lung Lobule.—The surface of the lung is covered with lines of connective tissue containing blood-vessels and lymphatics, with pigment either within the latter or free, the lines marking off little polygons (Fig. 1568), which are the bases of pyramidal masses of pulmonary tissue known as the *lobules*. The shape of the latter within the depths of the lungs is not accurately known; those at the sharp borders are modifications of the typical ones at the surface. The bases of the pyramids at the surface are bounded by four, five, or six sides, the larger diameter varying from 10–25 mm. and the smaller from 7–12 mm. If the base be assumed to be square, the average breadth would be 12.57 mm.[6] The average height is 13 mm. The lobules are separated from one another by a layer of connective tissue containing

[1] The latest and most elaborate work on this subject is Narath's Der Bronchialbaum der Säugethiere und des Menschen, Stuttgart, 1901.
[2] Archiv f. Anat. u. Phys., Anat. Abth., 1887.
[3] Human Embryology, 1892.
[4] Archiv f. mikro. Anat., Bd. lvi., 1900.
[5] Zeitschrift für Heilkunde, Prag., Bd. x., 1890.
[6] Bibliographie Anatomique, 1898.

vessels. Each lobule is entered by an *intralobular bronchus* (.5–1 mm. in diameter), accompanied by its artery,—not quite at the apex of the pyramid, but slightly to one side of it. The bronchus divides into two, at an angle of from 90°–100°, a little above the middle of the lobule, having previously given off two or three collateral branches to its upper part. In the third quarter of the lobule the two subdivisions (2–3 mm. in length) again split, with about the same degree of divergence as the parent stems, but in a plane at right angles to that of the previous splitting. This is repeated in three or four successive bifurcations, a varying number of collateral branches being given off. Thus the number of branches in the third quarter is much increased; but it is in the last quarter and towards the periphery of the lobule throughout that the tubes break up into the great number of truly ultimate bronchi. The various collaterals, spreading and even reascending, undergo subdivision also. Laguesse and d'Hardiviller[1] estimate the number of *terminal bronchi* (**ductuli alveolares**) within a single lobule at from fifty to one hundred or even more. The slightly dilated distal extremity of the terminal bronchus communicates with from three to six spherical cavities, the *atria* of Miller[2] (so named by him from the resemblance to the arrangement of an ancient Roman house). The atria, in turn, communicate with a group of larger and irregular cavities or *air-sacs* (**sacculi alveolares**), into which directly open the ultimate air-spaces, the *alveoli* or *air-cells* (**alveoli pulmonis**). The latter open not only into the air-sacs, but also into the atria, the dilated distal part of the terminal bronchus being likewise beset with scattered alveoli.

FIG. 1571.

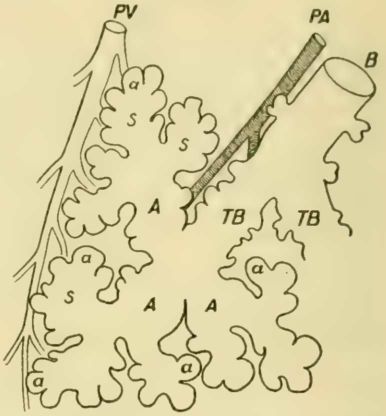
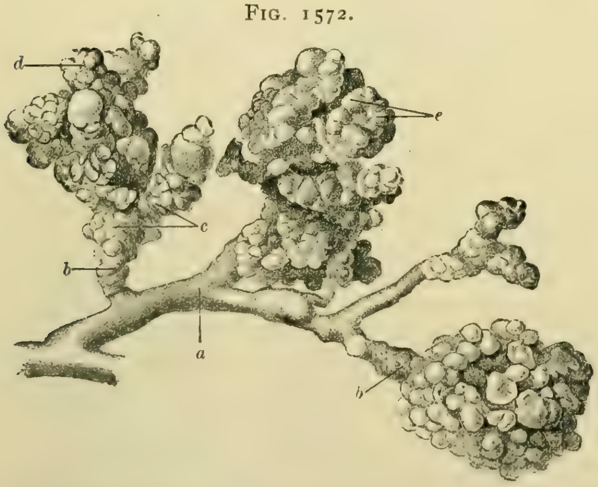


Diagram showing relations of terminal subdivisions of air-tubes. *B*, bronchiole ending in terminal bronchi (*TB*); latter divide into atria (*A*), each of which communicates with several air-sacs (*s*) into which open the alveoli (*a*); *PA*, branch of pulmonary artery follows bronchiole; *PV*, pulmonary vein at periphery of lung-unit. (*After Miller.*)

Miller holds that the terminal bronchus, the air-chambers connected with it, together with the vessels and nerves, is the true lung-unit, and calls it the lobule. We cordially agree that this is the true *lung-unit*, and propose that name for it, retaining the term "lobule" for the above-described more or less isolated portion of the lung which is surrounded by connective tissue and vessels and receives a single intralobular bronchus and artery. In some animals the lobules are perfectly distinct; they may be isolated in the infant, and can be in the main easily made out in the adult. The lung-unit, on the other hand, is not surrounded by areolar tissue, and its limits can be determined only by reconstruction from microscopical sections; hence, apart from its minuteness, it is practically too much of an abstraction to deserve the name almost universally applied to something tangible.

FIG. 1572.

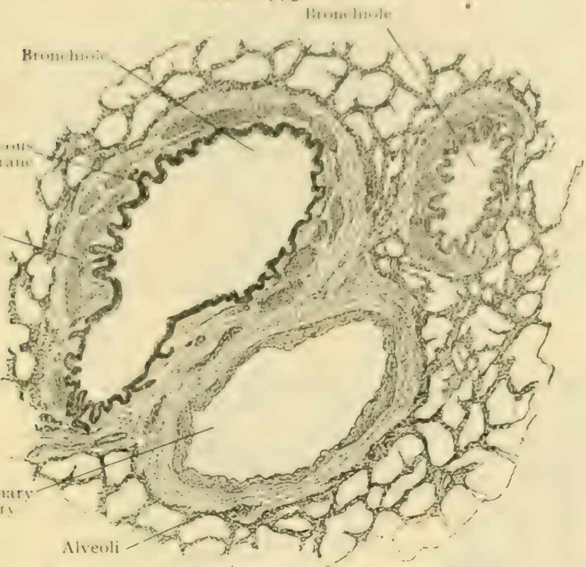


Corrosion-preparation of lung, showing lung-units. *a*, minute bronchus ending in terminal bronchi (*b*, *b*); *c*, atria; *d*, air-sac; *e*, alveoli. × 8.

[1] Bibliographie Anatomique, 1898.
[2] Journal of Morphology, 1893. Archiv f. Anat. u. Phys., Anat. Abth., 1900.

The intralobular bronchus is accompanied by some areolar tissue, and certain fibrous prolongations extend into the lobule from the connective tissue disposed about its surface. Although superficially these appear to divide the lobule into from four to twelve parts, they penetrate but a short distance. They are not real partitions, and the subdivisions they suggest have no morphological significance.

FIG. 1573.

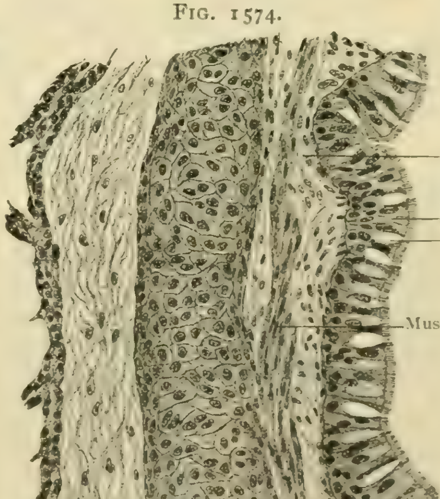


Section of lung, showing small air-tubes and branch of pulmonary artery. × 35.

Structure.—As far as their entrance into the lungs, the bronchi possess essentially the same structure as the trachea. After the division of the bronchus within the lung, the cartilage-rings are replaced by irregular angular plates, which appear at longer and longer intervals until they finally cease, the last nodules usually marking the points of bifurcation of the bronchi. Within the walls of bronchioles of a diameter of 1 mm. or less cartilage is seldom present. As the cartilage disappears the unstriped muscle broadens into a continuous layer, which, however, gradually becomes thinner as the air-tube diminishes, and extends only as far as the terminal bronchi. Around the circular openings, by which the latter communicate with the atria, the muscle is arranged as a sphincter-like band (Miller).

The walls of bronchi of medium size consist of three coats, which from without in are: (1) an external fibro-elastic tunic which encloses the cartilage and blends with the surrounding lung-tissue; (2) a usually incomplete layer of involuntary muscle composed of circularly disposed elements; (3) the mucosa, consisting of a stratum of compact elastic fibres next the muscle, the fibro-elastic stroma and the ciliated columnar epithelium. Mucous glands, similar to those of the trachea, are present, decreasing in number and size until the bronchus approaches 1 mm. in diameter, when they disappear. Their chief location is outside the muscular layer, which is pierced by the ducts. In addition to diffused cells within the mucosa, more definite aggregations of lymphoid tissue occur as minute lymph-nodules along the bronchi, the points of bifurcation of the latter being their favorite seats.

FIG. 1574.



Portion of wall of small bronchus. × 180.

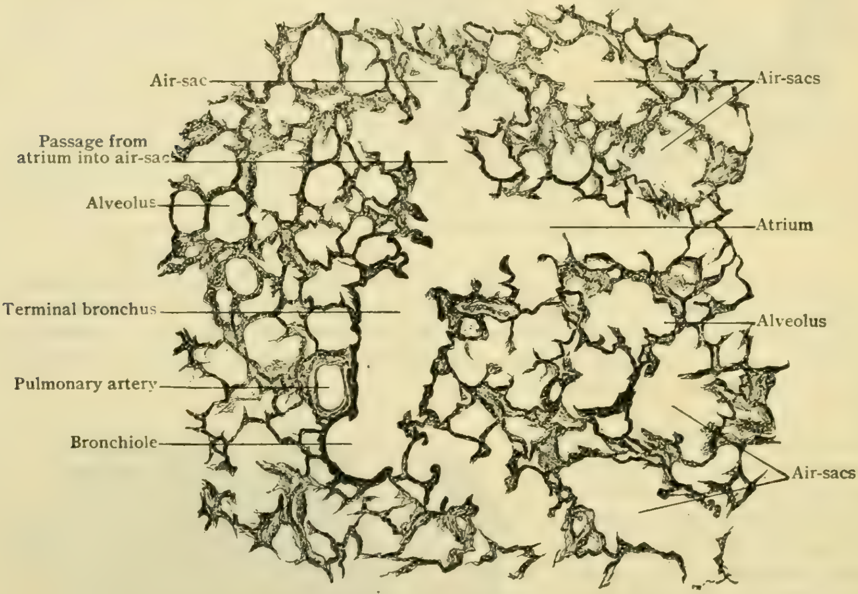
The epithelium lining the air-tubes retains the ciliated columnar type, with many

goblet-cells, as far as the smaller bronchi. Within these the ciliated cells are replaced by simple columnar elements which, in turn, give place to low cuboidal cells within the proximal part of the terminal bronchi. Towards the termination of the latter, transition into a simple squamous epithelium takes place.

The walls of the air-spaces—the atria, the air-sacs, and the alveoli—have essentially the same structure, consisting of a delicate fibro-elastic framework which supports the blood-vessels and the epithelium. Within the adult lung the latter is simple and is represented by two varieties of cells, the large, flat, plate-like elements (.020–.045 mm.) and the small nucleated polygonal cells (.007–.015 mm.) occurring singly or in limited groups between the plates. Before respiration and the consequent expansion of the air-spaces take place, the cells lining these cavities are small and probably of one kind. The groups of the smaller cells are larger, more numerous, and more uniformly distributed in young animals than in old ones, in which they are often represented by single cells irregularly disposed.

The adjacent alveoli share in common the interposed wall, which consists of the two layers of delicate elastic membrane beneath the epithelium lining the alveoli and

FIG. 1575.

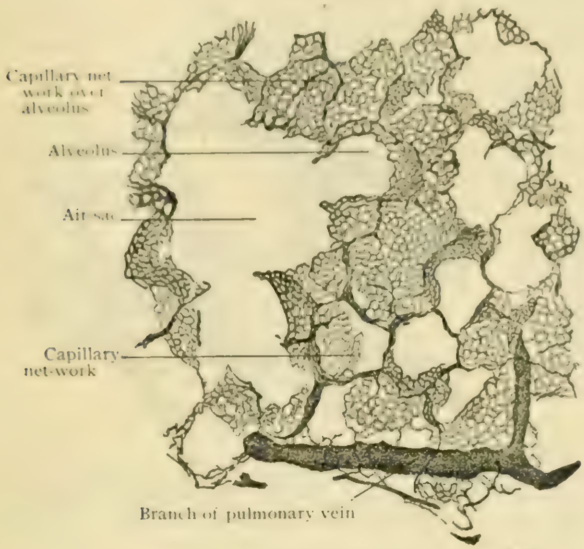


Section of lung, showing general relations of divisions of air-tubes. × 50.

the intervening capillary net-work, supported by a delicate framework of elastic fibres. The capillary net-work is noteworthy on account of the closeness of its meshes, which are often of less width than the diameter of the component capillaries. The latter are not confined to a single plane, but pursue a sinuous course, projecting first into one alveolus and then into the one on the opposite side of the interalveolar septum. The capillaries are, therefore, excluded from the interior of the air-cells by practically only the attenuated respiratory epithelium, the large plate-like cells lying over the blood-vessels while the small cells cover the intercapillary areas. Distinct intercellular apertures or stomata, formerly described as affording direct entrance from the alveoli into definite lymphatics, probably do not exist. That, however, inspired foreign particles may pass between the epithelial cells into lymph-spaces within the alveolar wall and thence into lymphatics, to be transported to more or less distant points, is shown by the gradual accumulation of carbonaceous and other particles within the interlobular tissue and the lymph-nodules along the course of the lymphatic vessels. Such accumulations may acquire conspicuous proportions, the entire interlobular septum appearing almost black. In view of the very frequent presence of pigment-loaded leucocytes within the alveoli, as well as outside the alve-

olar walls, it is highly probable that such cells are important agents in transporting the particles of inspired carbon through the walls of the air-cells. Additional particles, however, usually occupy the cement-substance between the alveolar epithelial cells, sometimes lying apparently within the cytoplasm of the latter.

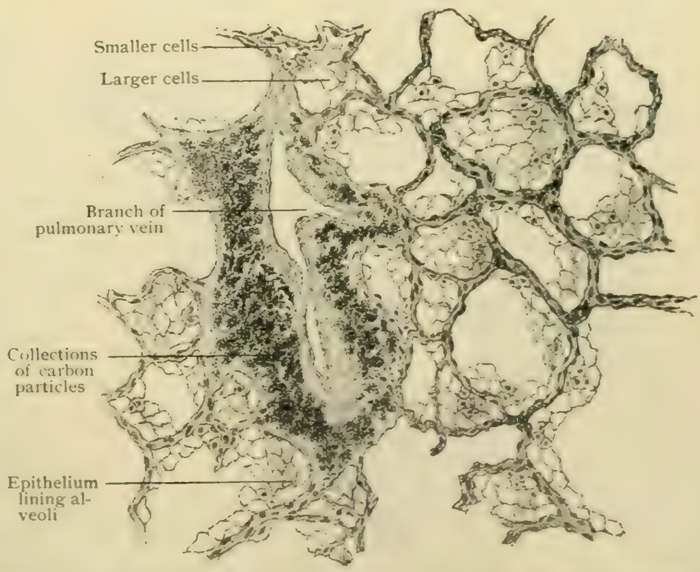
Fig. 1576.



Portion of injected and inflated lung. × 80.

Blood-Vessels of the Lung.—The *pulmonary artery*, serving not for the nutrition of the lung but for the aëration of the blood, is very large,—at first larger than the bronchus, which it follows very closely throughout its ramifications to the terminal bronchi. Situated at first anterior to the bronchus, it passes onto its superior and then onto its outer side, and in most cases twists around the bronchus, so as finally, when deep in the lung, to reach its dorsal aspect. This is very different from Aeby's alleged crossing of the main bronchus. The arterial branches accompanying the apical bronchus are in the main anterior to the tubes in the right lung and behind them in the left. According to Narath, the general course of the artery along the main bronchus is between the ventral and dorsal branches; but, as he states, this is not constant. We have found certain ventral bronchi in the lower part of the lung with the artery before them. An *intralobular branch* enters each lobule near the apex with the bronchus, and follows its ramifications until the ultimate bronchi have ended in the air-chambers of the lung-unit. The terminal arterioles are in its interior until they break up into capillaries in the walls of the alveoli. Side branches, *interlobular arteries*, run in the connective tissue between the lobules. It is from these, according to Miller, that the subpleural net-work is filled; formerly the latter was held to be supplied by the bronchial arteries.

Fig. 1577.

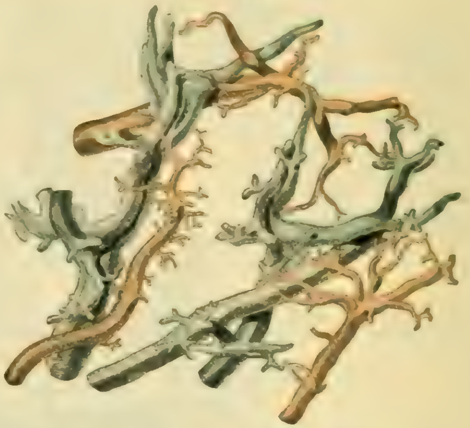


Section of lung, showing collections of particles of carbon in perivascular connective tissue. × 140.

The *pulmonary veins*, which return the aërated blood to the left auricle, are also large when they leave the hilum,—two on each side, one near the top and the other

near the bottom. They arise from the capillaries in the walls of the air-chambers, running first on the outside of the lung-units, unite with others, and ramify in the connective tissue about the lobules, so that, first in the lung-units and then in the lobules, the circulation is from the centre towards the periphery. As they ascend to the hilum they unite with others and form trunks that accompany the bronchi, lying in the main lower and to the inner side of the latter. Corrosion preparations (Fig. 1578) show very clearly that the small arteries travel in close company with the bronchi, while the veins course by themselves.

FIG. 1578.

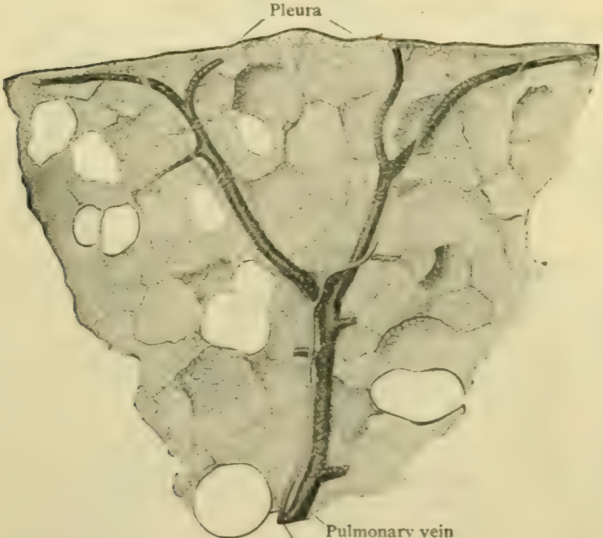


Portion of injected lung, showing relation of blood-vessels to bronchi; pulmonary arteries (blue) accompanying bronchi (white); pulmonary veins (red) at periphery of lobule. × 2

The *bronchial arteries* carry the blood for the nutrition of the lungs, especially that of the air-tubes, the lymph-nodes, the walls of the blood-vessels, and the areolar tissue about them; hence they follow the course of the bronchi. They are in communication with the interlobular system of the pulmonary arteries.

The *bronchial veins* are very irregular. Both anterior and posterior are described. The former carry the blood back from the bronchi and the tissues about them, becoming perceptible at the bronchi of the third order (*i.e.*, the branches of the first branches) and running to the hilum anterior to the bronchi, two with each. The posterior bronchial veins appear at the back of the hilum and, without any close connection with the bronchi, anastomose with other veins at the back of the roots of the lungs.

FIG. 1579.



Section of injected lung, showing lymphatic accompanying peripheral branch of pulmonary vein. × 60. (*Miller.*)

Anastomoses between the Pulmonary and the Bronchial Systems.—Not only do the capillaries at some places drain into either system of veins, but important communications occur between both the arteries and the veins. (*a*) The bronchial arteries as they enter the lungs give off occasional branches which, running for some distance beneath the pleura, suddenly plunge into the lung to anastomose with an interlobular artery. Such a branch may arise from an œsophageal artery. There are also deep connections between the arteries of the two systems on or near the secondary bronchi and their branches. (*b*) The communications between the two systems of veins are very extensive. Apparently all the blood from the smallest branches of the bronchial arteries returns by the pulmonary veins; and, moreover, the bronchial veins about the larger bronchi have free communication with those of the pulmonary system. According to Zucker-

kandl,[1] the pulmonary veins anastomose freely with those of the organs of the posterior mediastinum, and even of the portal system.

The *lymphatics* of the lung are very numerous. The deeper ones probably begin as lymph-spaces within the interalveolar septa, distal to the terminal bronchi, distinct lymphatics being found only along the arteries and veins. These communicate with the subpleural lymphatic plexus. Surrounding the walls of the terminal bronchi Miller found usually three lymph-vessels. The latter increase in size and number as the calibre of the air-tubes enlarges. On reaching the bronchi the lymphatics form plexuses along them which ultimately open into the lymphatic nodes, which are numerous in the hilum and in the roots of the lungs. According to Miller, where cartilage-rings are present a double net-work exists, one on each side of the cartilage, the inner lying within the submucosa. The lymph-nodes of the lungs are deeply pigmented, owing to the colored particles of foreign substances inspired.

Nerves.—The nerves of the lungs, from the pneumogastrics and sympathetics, form the very rich anterior and posterior pulmonary plexuses about the roots, whence they enter the lungs, running along the branches of the bronchial arteries and the bronchi to their ultimate distribution in the septa between the alveoli (Retzius, Berkley). The nerves are destined chiefly for the walls of the blood-vessels and of the air-tubes. Berkley describes interepithelial end-arborizations within the smaller bronchi.

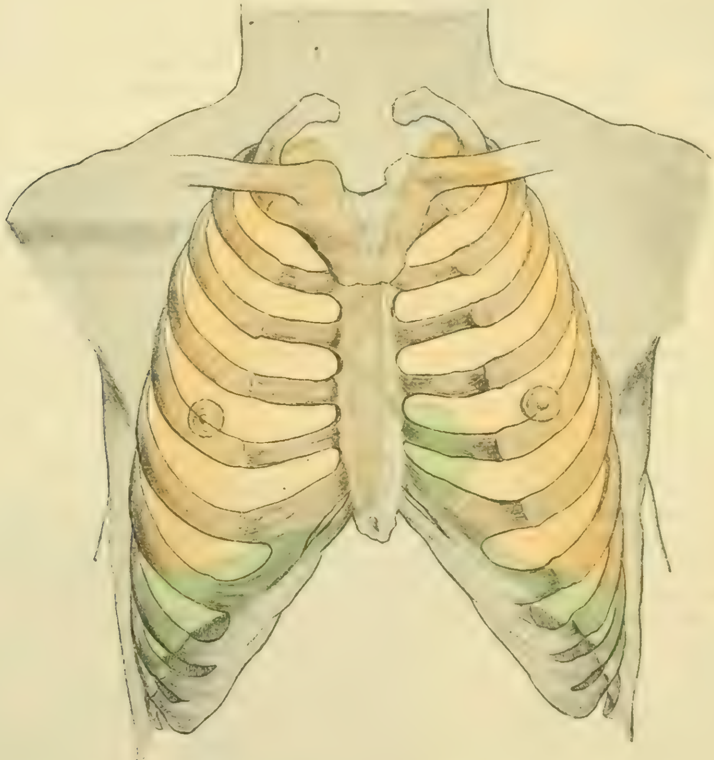
THE RELATIONS OF THE LUNGS TO THE THORACIC WALLS.

The relations of the median and diaphragmatic surfaces of the lungs have been given (page 1844). The apex rises vertically about 3 cm. above the level of the upper border of the first costal cartilage and about 1 cm. above the level of the clavicle. These distances are to be reckoned on a vertical plane, not on the slanting surface of the root of the neck. They vary extremely, depending, as they do, on the formation of the body. Thus a sunken chest, which means a very oblique first rib, would have more lung above the cartilage than a full chest with a more nearly horizontal first rib. In extreme cases the lung may rise as much as 5 cm., or as little as 1 cm., above the first cartilage. The plane of the inlet of the chest is made by the oblique first ribs. The fibrous parts enclosing it are dome-like, the roof of the cavity, to which the lung is closely applied, swelling upward perhaps 1 cm. above this oblique plane; the top of the lung, however, is never above the level of the neck of the first rib. It was formerly taught that the right lung rises higher than the left. As a rule, there is no appreciable difference between the two sides. The most that can be said for the old view is that, if there be some trifling difference, it is probably rather more often in favor of the right. The anterior borders of the lungs descend obliquely behind the sterno-clavicular joints, and curve forward so as to nearly, or quite, meet in the median line on the level of the junction of the manubrium and body of the sternum. Below this the right lung extends a little across the median line and the left recedes slightly from it. The right border leaves the sternum at the sixth right costal cartilage, to which it has gradually curved, runs along that same cartilage, or a little above it, to its junction with the sixth rib, then crosses the ribs, passing the eighth at about the axillary line, and reaches the spine at the eleventh rib or a little higher, the guide being the spine of the tenth thoracic vertebra. The lowest part of the lung is on the side at the axillary line or behind it, but the line thence along the back, although rising a little, is very nearly horizontal. The course of the border of the left lung is essentially the same, except that, leaving the sternum at the fourth cartilage, or at the space above it, the border describes a curve with an outward convexity, exposing a large piece of the pericardium, and turns forward to end as the lingula opposite the sixth cartilage, some distance to the left of the sternum. As this point depends on the development of the lingula, it cannot be stated accurately. It may be said in general to be 3 or 4 cm. to the left of the median line. The greatest depth of this curve is in the fourth intercostal space, about 5 cm. from the median line. The course of the inferior border along the side and back is practically that of the right one, although, perhaps, the left lung may descend a trifle lower at the side. At the back the lower borders are very symmetrical.

[1] Sitzungsberichte d. Wiener Akad., Bd. lxxxiv., 1881.

Apart from variations in the lungs themselves, the different shapes and sizes of the chest, with the consequent differences in the inclination of the ribs, make these relations very uncertain, especially at the side. In forced respiration there is no change in the relations of the top of the lungs and the dome of the pleura, as they are always in close apposition, and but little change in the first part of the anterior borders. The latter, however, approach one another behind the sternum in forced inspiration, a considerable advance of the left lung taking place at the cardiac notch. We agree with Hasse that during inspiration the anterior parts of the lungs rise just about as much as the thoracic walls. The greatest changes of relations are below and at the side. It is said that in the axillary line the border may descend as much as from 3–4 cm., and at the back as much as 3 cm. According to Hasse,[1] the lower border of the lung in the axillary line never descends nearer to the lower edge of the thoracic wall than 7 cm. on the right and 5 cm. on the left. He finds that in

FIG. 1580.



Semidiagrammatic reconstruction, showing relations of pleural sacs (blue) and lungs (red) to thoracic wall; anterior aspect.

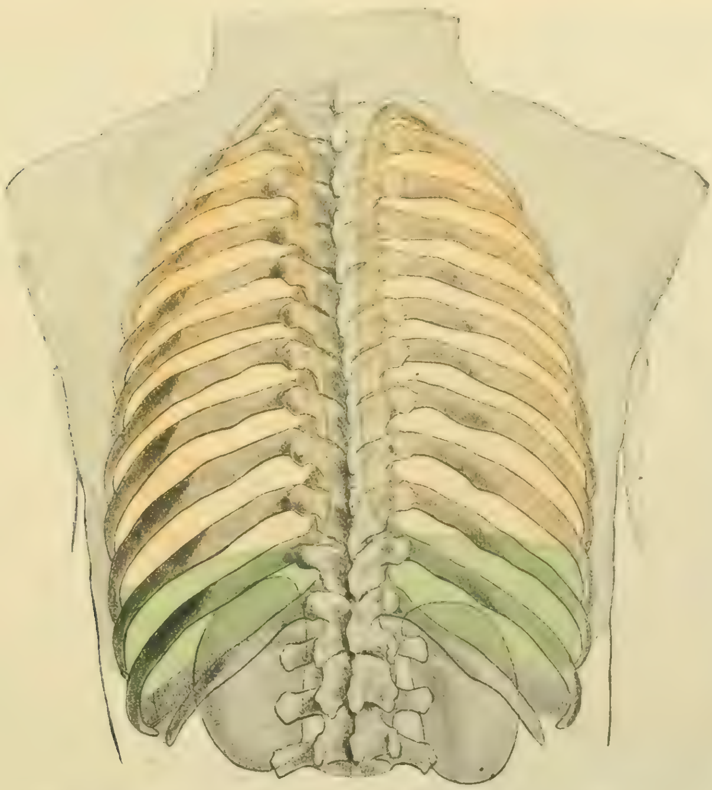
extreme expiration the lower borders of the lungs rise in the axillary lines to 13 cm. on the right and 14 cm. on the left above the lower border of the chest. He states also that the anterior borders may withdraw to the parasternal lines (vertical lines dropped from the inner third of the clavicles), which to us appears excessive. In our opinion, the great factor in the expansion of the lungs is the increase in the various diameters of the chest rather than the changes of relation of the borders of the lungs to the walls.

The *relations of the fissures* to the surface are rather variable. The chief ones ascend from the hila and reach the posterior surface at the sides of the vertebral column, generally at different levels, the right being the lower. We must, therefore,

[1] Die Formen des menschlichen Körpers und die Formänderungen bei der Athmung, Jena, 1888 and 1890.

trace the course of each fissure separately. The fissure of the right lung leaves the vertebral column either at the fifth rib or at the interspace above or below it. The fissure tends to follow the fifth rib, being in the axillary line still, either beneath it or beneath an adjacent intercostal space. Towards the front the fissure gets relatively lower, ending in most cases either at the fifth space or beneath the sixth rib, near the junction of the bone and cartilage, from 5–10 cm. from the median line. The secondary fissure of the right lung leaves the chief one somewhat behind the axillary line, and, running about horizontally forward, ends at a very uncertain point. Rochard, in his small series of twelve observations, found it at the third intercostal space seven times. Once it was higher and four times lower. The fissure of the left lung leaves the side of the spine at a less definite point, ranging in most cases from beneath the third rib to the upper border of the fifth, and being sometimes even lower. At the axillary line it is at the fifth rib a little more often than at any other particular point, but it is almost as often at the fourth and more often somewhere below the fifth. Its termination is more constant than its course, being beneath the sixth rib, or the space above or below it, usually from 6–11 cm. from the median line.[1]

Fig. 1581.



Semidiagrammatic reconstruction, showing relations of pleural sacs (blue) and lungs (red) to body-wall; posterior aspect.

The *relations of the bronchi* to the chest-wall have not been studied on a sufficient number of bodies for satisfactory conclusions. Blake[2] has had X-ray photographs taken of an adult body hardened with formalin, the bronchi being injected with an opaque substance. The bifurcation was normally placed. We attach the

[1] Gazette des Hôpitaux, 1892. Our description is almost wholly a synopsis of Rochard's work.
[2] American Journal of the Medical Sciences, 1899.

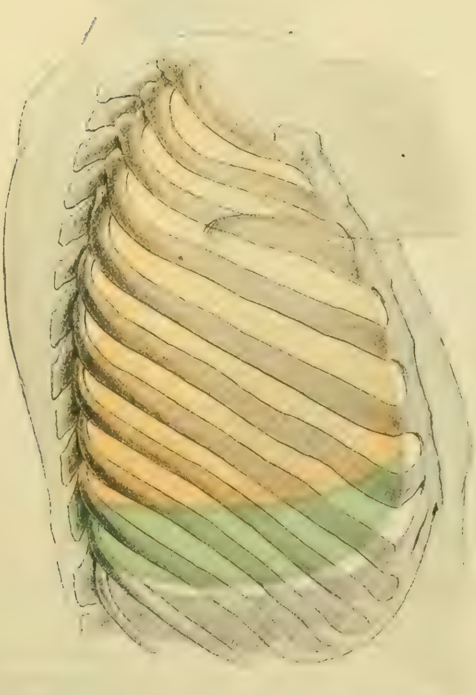
most importance to the course of the main bronchus : "On the posterior wall the course of the left bronchus is from a point to the right of the fourth thoracic spine to a point on the eighth rib three inches to the left of the spine. The course of the right bronchus is from the same point above to a point on the eighth rib two inches to the right of the spine. On the anterior wall the course of the left bronchus is from the lower part of the second right sterno-chondral articulation to a point on the fifth rib just internal to the mammillary, and of the right bronchus from the same point above to the intersection of the fifth rib with the parasternal line." The hilum is opposite the bodies of the sixth and seventh thoracic vertebræ and a part of the adjacent ones. (Figs. 1569 and 1570.)

(The changes of the relations of the lungs during growth and in old age are considered with those of the pleuræ.)

THE PLEURÆ.

The pleuræ are a pair of serous membranes disposed one over each lung and then reflected so as to line the walls of the cavity containing it, thus forming a distinct closed sac about each lung ; hence the pleura is divided into a *visceral* and a *parietal layer*. The latter is subdivided according to its situation into a mediastinal, a costal, a cervical, and a diaphragmatic part. The *visceral layer* closely invests the lung, following the surface into the depth of the fissures. It leaves the lung at the borders of the hilum and invests the root for a short distance (1–2 cm.), when it leaves the latter and spreads out as the *mediastinal pleura*, which is applied, back to back, to the pericardium, thus forming on each side a vertical antero-posterior septum between the lungs and the contents of the mediastina. The prolongation over the root is not quite tubular, since a triangular frontal fold extends from beneath the root to the inner side of the lung, growing narrower as it descends, to end at or near the lower borders. This is the *broad ligament of the lung* (**ligamentum latum pulmonis**). Its line of attachment to the lung often slants backward. The mediastinal pleura, besides being applied to the side of the pericardium, lies also against some of the structures of the other mediastina. Above it is in contact with the thymus on both sides, the superior vena cava on the right and the arch of the aorta on the left. The phrenic nerve descends on each side between it and the pericardium in front of the root of the lung. In the posterior mediastinum it lies against the left side of the descending aorta and the right of the upper part of the greater azygos vein. It is in contact with nearly the whole of the œsophagus on the right, and just before the latter passes through the diaphragm on the left also. It covers the gangliated cord of the sympathetic on both sides as it passes into the *costal pleura*, and is here stretched so tightly across the terminations of the intercostal veins as to keep their walls distended. Anteriorly it crosses the areolar tissue of the anterior mediastinum below the remnants of the thymus. It

FIG. 1582.

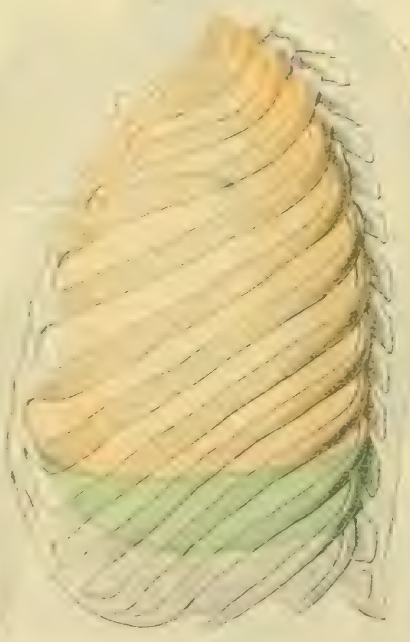


Semidiagrammatic reconstruction, showing relations of right pleural sac (blue) and lung (red) to thoracic wall ; lateral aspect.

is continued outward, both before and behind, to become the costal pleura, and is continuous above with the *cervical pleura* which lines the dome in the concavity of the first rib. It passes below into the *diaphragmatic pleura* which invests the upper surface of the diaphragm. Laterally, and still more behind, it follows for a certain distance the vertical fibres of the diaphragm, and then is reflected onto the thoracic wall so as to line a potential cavity between the two layers which, except for some little serous fluid, are here in apposition. Villous projections occur along the borders of the lungs, especially at the inferior border, where they form a dense, but very minute fringe, not over 1 mm. broad.

Relations of the Pleuræ to the Surface.—In some places the lungs and the pleuræ are always in the same relation; in others the pleuræ extend a certain distance beyond the lungs, which fill them in complete inspiration so that their outlines correspond; in other places the pleuræ extend so much beyond the lungs that even in the most extreme inspiration the latter do not reach the limits of the former. At the apices the relations of the lungs and pleuræ are constantly the same, both being in contact. All that has been said of the relation of one to the body-walls is true of the other. Behind the first piece of the sternum the relations are nearly the same, but below this level a space exists in the pleuræ into which the lungs enter during deep inspiration. This is notably the case at the left half of the body of the sternum. The pleuræ present inferiorly at the sides and behind a merely potential cavity between the diaphragm and the chest-walls, to the bottom of which (probably at the sides and certainly behind) the lungs can never descend. The pleuræ, however, never approach closely the lower border of the chest at the sides, for the diaphragm arising from the inner surface of the frame of the thorax takes up a certain amount of space, and above it the connective tissue fills the cleft so that the pleuræ do not descend to within 3 cm. of the lower border. In the subject used by Hasse the space in the axillary line below the reflection of the pleuræ to the origin of the diaphragm (the lower border of the chest) was 5.5 cm. on the right and 4 cm. on the left.

Fig. 1583.

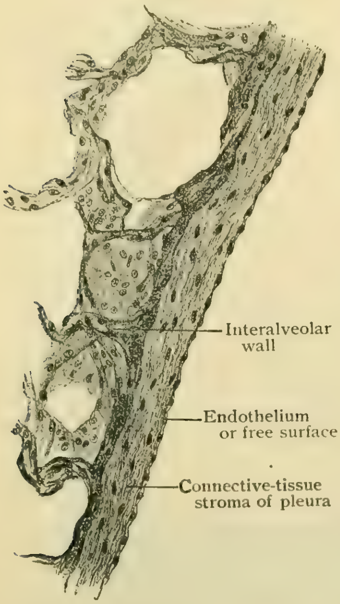


Semidiagrammatic reconstruction, showing relations of left pleural sac (blue) and lung (red) to thoracic wall; lateral aspect.

The **outlines of the pleuræ** are as follows. Beginning at the apex, about 3 cm. vertically above the cartilage of the first ribs, the anterior borders descend behind the sterno-clavicular joints to meet at the median line at the level of the second cartilage. They then descend together, or nearly so, behind the left half of the body of the sternum. Half-way down the body of the sternum the left pleura tends to diverge to the left, passing from behind the sternum usually at about the junction with the sixth cartilage. The right pleura descends more nearly in a straight line and turns suddenly outward at the level of the seventh cartilage. Laterally the pleuræ run pretty close to the cartilages of the sixth rib on the left and the seventh on the right, but both cross the eighth rib at or near the junction of bone and cartilage. In the axillary line, or a little behind it, the pleura crosses the tenth rib at about the same place on both sides, and usually ends posteriorly opposite the lower part of the twelfth thoracic vertebra, the right one being often the lower (Tanja). While such is the general outline, there are considerable and important variations both anteriorly and pos-

teriorly. The former teaching, according to which the left pleura describes at the front a curve somewhat similar to that of the left lung, is quite wrong. However, the point at which it leaves the sternum, the extent to which it is in contact with the right pleura, and the distance the latter advances under the sternum are all very uncertain. The most important point is the extent to which the pleura covers the pericardium. According to Sick's[1] observations on twenty-three bodies of adults, the reflection of the left pleura at the fifth cartilage was in seventeen either behind the sternum or just at its border; thus it left the sternum at a higher point only six times. At the sixth cartilage the pleura was ten times behind the sternum and less than 1 cm. from it in six. At the seventh cartilage it was five times at the border of the sternum or behind it and five times not over 1 cm. external to it. It left the sternum close to the seventh cartilage five times. Tanja,[2] however, found the left pleura leaving the sternum at the fourth cartilage in four of fourteen bodies ranging from eight years upward. The left pleura may exceptionally cross the median line, and, it is said, may not extend forward as far as the sternum; but such a condition must be very exceptional. There is considerable variation as to the depth of the descent posteriorly. Tanja never found the lower fold at the back in the adult higher than the middle of the last thoracic vertebra. It may descend to the first lumbar and even to the second.

Fig. 1584.



Section through free edge of lung, showing visceral pleura. × 150.

Structure.—The pleura, like other serous membranes, consists of a stroma-layer composed of bundles of fibrous tissue intermingled with numerous elastic fibres. The general disposition of the connective-tissue bundles is parallel to the free surface, although the bundles cross one another in various directions. The free surface of the pleura is covered with a single layer of nucleated endothelial cells (from .020–.045 mm. in diameter), which rest upon a delicate elastic limiting membrane differentiated from the stroma-layer. The existence of definite openings, or stomata, between the endothelial plates, leading into the numerous lymphatics of the pleura, is doubtful.

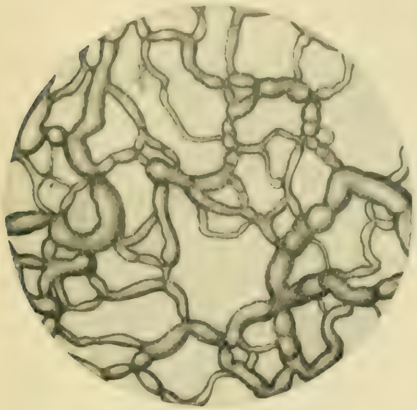
The *subserous layer* is very thin over the lung where it is continuous with the elastic interlobular tissue. In the mediastinum it has a firm fibrous backing so as to make a strong and dense membrane. The cervical pleura is extremely thick and resistant, being strengthened by fibrous or muscular bands from the system of the scaleni muscles spreading into it from behind, as well as by expansions from the areolar tissue about the trachea, œsophagus, and subclavian vessels. The costal pleura has a subserous layer, known as the *fascia endothoracica*, through which it is attached to the thoracic walls less closely than elsewhere. This fascia is thickest near the top. The ribs show clearly through the pleura of the opened thorax, appearing light in contrast to the congested intercostal spaces. The subserous layer is hardly existent beneath the diaphragmatic pleura, but at the sides of the thorax there is a considerable space below the reflection of the pleura from the diaphragm, occupied by areolar tissue connecting the diaphragm and walls.

Blood-Vessels.—The *arteries* of the visceral pleuræ have been shown by Miller to come from the system of the pulmonary arteries instead of from that of the bronchial, as previously believed. They form a fine net-work over the lung. Those of the parietal pleuræ come from the aortic and superior intercostals, the internal mammaries, the mediastinal, the œsophageal, the bronchial, and the phrenic arteries.

[1] Archiv f. Anat. u. Phys., Anat. Abth., 1885.
[2] Morphol. Jahrbuch, 1891.

The *veins* of the visceral pleuræ are tributary to the pulmonary system; those of the parietal pleuræ open into the veins corresponding to the arteries. It is important to note that the intercostal spaces have many veins and that the pleura over the ribs has but few, these chiefly communicating with the veins above and below them. Owing to the arrangement by which the intercostal veins are kept open, the venous circulation of the parietal pleuræ is under the influence of the suction power both of respiration and of the heart.

FIG. 1585.



Injected lymphatics of pleura, seen from surface. × 75. (*Miller.*)

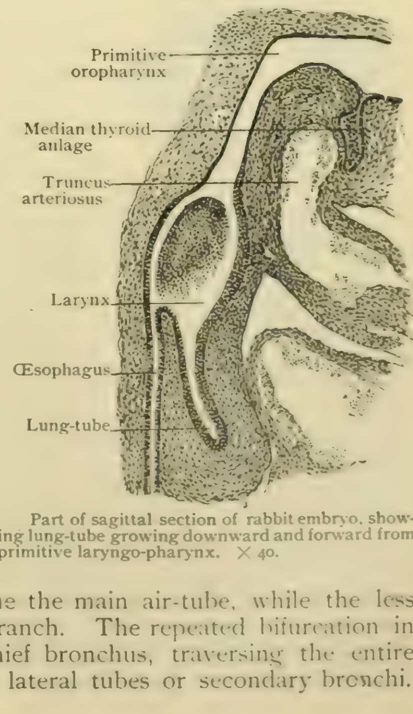
The *lymphatics* are numerous over the lungs and also in the intercostal spaces. Those of the parietes open into both intercostal and substernal lymph-nodes.

Nerves.—The nerves of the visceral pleuræ are from the pulmonary plexuses, containing both pneumogastric and sympathetic fibres; those of the parietal pleuræ are from the intercostal, the phrenic, the sympathetic, and the pneumogastric nerves.

Development of the Respiratory Tract.—The respiratory tract develops as an outgrowth from the primitive digestive tube. Early in the third week, in embryos of little over 3 mm. in length, a longitudinal groove appears on the ventral wall of the fore-gut, extending from the primitive pharynx above well towards the stomach below. This groove becomes deeper, constricted, and finally separated from the fore-gut as a distinct tube, the differentiation resulting in the production of two canals,—the respiratory tube in front and the œsophagus behind. Separation and completion of the former proceeds from the lower end of the groove upward as far as the pharynx, into which both œsophagus and air-tube open. The cephalic end of the latter becomes enlarged and forms the larynx, the adjoining portion corresponding to the trachea.

The Lungs.—The distal extremity of the primary respiratory tube soon enlarges and becomes bilobed, pouching out on each side into a lateral diverticulum which represents the primitive bronchus and lung. These pulmonary diverticula elongate and subdivide, the right one, which is somewhat the larger, breaking up into three secondary divisions and the left into two, thus early foreshadowing the later asymmetry of the lung-lobes. Since the primary air-tube lies medially in the dorsal attachment of the septum transversum, the pulmonary buds extend laterally and backward into the dorsal parietal recesses (later the pleural cavities), carrying before them a covering of mesoblast.

FIG. 1586.



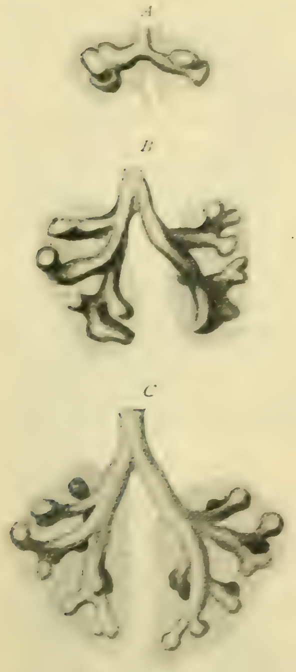
Part of sagittal section of rabbit embryo, showing lung-tube growing downward and forward from primitive laryngo-pharynx. × 40.

The primary lobes increase in size and complexity as additional outgrowths arise by the division of the enlarged terminal part of each diverticulum. The resulting divisions, or new bronchi, are at first equal, but soon grow at an unequal rate, the one elongating most rapidly becoming so placed as to continue the main air-tube, while the less rapidly elongating division becomes a lateral branch. The repeated bifurcation in this manner results in the production of a chief bronchus, traversing the entire length of the lung, into which open numerous lateral tubes or secondary bronchi.

The latter, from their relation to the principal stem of the pulmonary artery which accompanies the chief air-tube, are regarded as dorsal and ventral. They alternate with one another, and usually number four in each series; not infrequently, however, the third dorsal bronchus fails to develop, thereby leading to a corresponding reduction and asymmetry in the series. In the left lung the first dorsal bronchus springs from the corresponding ventral bronchus instead of the chief tube, as on the right side. This arrangement is probably associated with the fusion of the upper and middle lobes in the left lung.

The secondary bronchi elongate and give origin to tertiary bronchi, and these, in turn, to air-tubes of lesser calibre, until the ramifications end as terminal bronchi and the associated divisions—atria, air-sacs, and alveoli—of the lung-unit. Since the fore-gut is clothed with entoblast, it is evident that the lining of the respiratory tract is derived from the same germ-layer. At first the outpouchings of the respiratory tube are surrounded by relatively thick masses of mesoblastic tissue. Since the growth of the latter fails to keep pace with the increasing mass and complexity of the bronchial tree, the intervening mesoblast becomes greatly reduced. Coincidently the mesoblast becomes vascular and rich net-works of blood-vessels appear between the terminal divisions of the epithelial tubes, later forming the chief constituents of the alveolar walls. The mesoblastic tissue remains between the lobules as the interlobular septa, as well as contributing all constituents of the walls of the air-tubes except the lining epithelial and its glandular derivatives, which are entoblastic. By the close of the fourth month of fœtal life the low columnar cells lining the trachea and bronchi acquire cilia. The peripheral layer of the mesoblast invaded by the lungs eventually becomes the investing serous membrane, or pulmonary pleura, all parts of which are of mesoblastic origin. Before inflation occurs at birth, the lung-tissue is comparatively solid and resembles in many ways a racemose gland. With the expansion following the establishment of respiration, the epithelial cells lining the ultimate air-spaces undergo stretching, a majority of the small polygonal elements becoming converted into the flat plate-like cells seen in the functionating lung.

FIG. 1587.

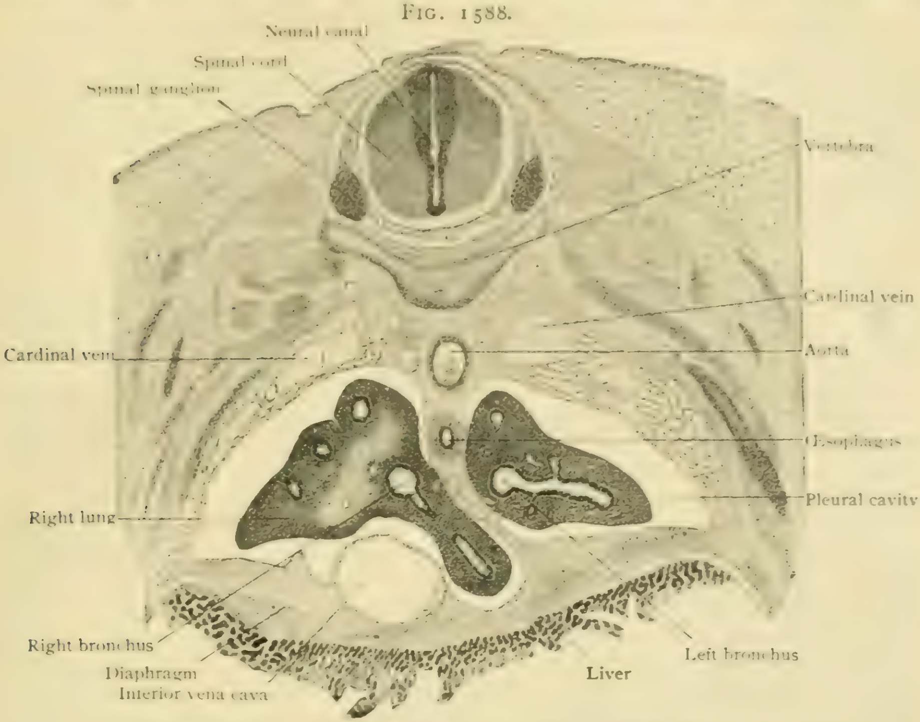


Reconstructions of developing bronchial tree. *A*, fourth week; *B*, beginning of fifth week; *C*, close of fifth week. (*His-Merkel.*)

The Larynx.—The pharyngeal end of the primary respiratory tract is surrounded in front and laterally by a U-shaped ridge, known as the *furcula*, anterior to which lies the paired posterior anlage of the tongue. The anterior portion of this ridge forms a median elevation from which is formed the epiglottis; the lateral portions constitute the *arytenoid ridges* which bound the laryngeal aperture at the sides. During the fourth month a furrow on the median side of the arytenoid ridges marks the first appearance of the ventricle of the larynx, the margins of the groove later becoming the vocal cords. About the eighth week the cartilaginous framework is indicated by mesoblastic condensations. The thyroid cartilage consists for a time of two separate lateral mesoblastic plates, in each of which cartilage is formed from two centres. These are regarded as representing the cartilages of the fourth and fifth branchial arches. As development proceeds the cartilages formed at these centres fuse and extend ventrally until they unite anteriorly in the mid-line. Chondrification is completed comparatively late, and when incomplete or faulty may result in the production of an aperture,—the thyroid foramen. The anlages of the cricoid and arytenoid cartilages are at first continuous, but later become differentiated by the appearance of a centre of chondrification for each arytenoid and an incomplete ring, for a time open behind, for the cricoid. The latter thus resembles in development a tracheal ring, with which it probably morphologically corresponds. The cartilages

of Wrisberg (cuneiform) and of Santorini (cornicula laryngis) are formed from small portions separated from the epiglottis and the arytenoids respectively. The

FIG. 1588.



Portion of transverse section of rabbit embryo, showing developing lungs. × 30.

epiglottis and the cricoid possibly represent rudiments of the cartilages of the sixth and seventh branchial arches.

FIG. 1589.

Section of fœtal lung, showing compact character of uninflated pulmonary tissue. × 200.

Changes in the Relations of the Lungs and Pleuræ to the Chest-Walls.—At birth the thorax is small, relatively very narrow, with the lower part undeveloped and with more horizontal ribs. The costal cartilages are relatively long to the ribs proper. Nevertheless, at birth and in childhood the borders of the lungs have very nearly the same relations to the chest-walls that they have in the adult, excepting in front. Here they do not extend so far forward, and consequently the pericardium is at first less covered by the left lung. The course of the pleuræ is much less certain. Tanja found much variation in that of the lower borders of the pleuræ, the latter crossing all the costal cartilages fourteen times in twenty-four bodies of children under two years and not a single time in the adult. In eleven of the same series the pleuræ did not meet behind the sternum, and in nine the left pleura did not reach it. He found neither of these conditions even once in the adult. According to Mehnert, there is a very slight progressive sinking of

the lower border of the lung during the period preceding old age, which is more rapid than the senile increase of the declination of the ribs.

PRACTICAL CONSIDERATIONS: THE LUNGS AND PLEURÆ.

The Lungs and Pleuræ.—Many of the most important practical questions arising in cases of injury or disease of the lungs and pleuræ can be answered only after a physical examination, the value of which will depend primarily upon complete knowledge of the normal phenomena associated with respiration. Such knowledge must be based upon acquaintance with the structural conditions that influence the sounds caused by a current of air entering and leaving the normal air-passages and with the chief modifications caused by disease.

Only a few of even the most elementary facts bearing upon this subject can here be mentioned, but their consideration at a time when the pulmonary system is being studied can scarcely fail to be of practical value, and is necessary to an understanding of those symptoms of pulmonary or pleural injury or disease which have the most obvious anatomical bearing.

Anatomical Basis for Varied Character of Breath-Sounds.—The normal sounds of respiration vary with the situation of the air-passages examined. Their loudness is in direct proportion to their nearness to the larynx, so that *laryngeal*, *tracheal*, *bronchial*, and *vesicular* breathing sounds are here mentioned in the order that indicates progressively increasing softness.

These terms acquire pathological significance when breathing of one type is heard in a portion of the chest where it should not be heard. The nearness of the larynx to the surface and its inclusion of air, as if within a hollow box (West), make laryngeal sounds loud and noisy on both expiration and inspiration. In the trachea, part of which is deeper, and a portion of the walls of which is of soft muscular and fibrous tissue, both these sounds, as heard over the suprasternal notch, or over the lower cervical or upper dorsal vertebræ, while still loud, are softer and are raised in tone. Over the bronchi, heard best between the scapulæ (page 1842), they are both audible and are harsh, but have still further diminished in loudness. Over the pulmonary tissue inspiration has become soft and blowing and expiration can scarcely be heard. The reasons for these differences are as follows. The sounds of breathing are produced chiefly at or about the glottis, therefore distance from the larynx accounts for the diminution in loudness. The decrease in the diameter of the air-tubes accounts for the rise in pitch of the respiratory note. The entrance of the air into compartments of various sizes within the pulmonary tissue breaks up the air-column which carries the sound and distributes the vibrations, so that the sounds are muffled and soft (West).

If the bronchial tubes or tubules are obstructed, as from hyperæmia of the mucosa, or the presence of viscid secretion, the exit of air will be interfered with. and there will be "prolonged expiration."

In a broad way, it may be said that in cases in which vesicular breathing is diminished or absent the cause should be sought: (1) In obstruction (pseudo-membrane or fibrinous exudate). (2) In compression (aneurism, glandular swellings, mediastinal tumors). (3) In immobilization of the chest-wall on the affected side (fracture of rib, intercostal neuralgia, pleurisy or pleuritic adhesions). (4) In distention of the pleura by liquids or air (pneumothorax, empyema). If as a result of disease the vesicular structure is occupied by an exudate (as in pneumonia), the vibrations are conveyed more directly to the ear, expiration becomes audible, and, as consolidation increases, the sounds, first of the smaller bronchioles and then of the larger bronchi, replace the normal blowing sound, and "bronchial breathing" is established. If the cavity of the pleura is distended with air (*pneumothorax*), which separates the lung-tissue from the thoracic wall and conducts sound vibrations much less effectively than do solids, the breath-sounds will be feeble and distant or absent. If the pleural cavity is so filled with either air or fluid (*empyema*) that the lung is collapsed or compressed against the spine, the breath-sounds may be feeble or distant or entirely wanting over the front and sides of the chest, but bronchial breathing can be heard over the back. In exceptional cases of pleural effusion such breathing is also heard

over the sides and front, and it has been suggested that this is due to contact between a bronchus and a rib, the latter conveying the breath-sounds directly to the ear.

If the larynx or trachea is narrowed, the air has to pass through a constricted aperture, must do so at a greater rate, and will make a louder noise,—*stridor*.

Râles are caused by changes in the mucous and epithelial lining and contents of the air-passages. Like the normal breath-sounds, they are louder and noisier the nearer they are to the larynx or the larger the tubes in which they are produced.

Mucous râles are moist, are thought to be produced by the bursting of air-bubbles in viscid or watery mucus occupying the larger air-passages, as in bronchitis, and vary in character (*i.e.*, in fineness or coarseness, or in loudness) in accordance with the size of the tube that they occupy. The bubbling of air through the accumulating mucus in the larynx, trachea, and bronchi of a moribund person—the "death-rattle"—is an example of the larger kind of mucous râles.

Crepitant râles are dry râles, due, it is thought, to the gluing together of the opposing surfaces of a number of air-vesicles by an exudate, the entrance of air on inspiration then causing a fine crackling sound, "like that which is heard when a small bunch of hair near the ear is rolled backward and forward between the tips of the finger and thumb" (Owen). If a similar condition affects the lumen of a tube, it may produce larger râles, still dry, known as *rhonchi* (snoring) or *sibili* (hissing). Other factors enter into the production of râles, but the chief underlying anatomical conditions have been mentioned.

Air entering a cavity (*pulmonary vomicæ*, *bronchiectasis*) causes a sound resembling that produced by blowing into an empty bottle,—*amphoric*. A peculiar sound heard often in pneumothorax, and caused by the air from the fistulous communication with the lung entering the pleural cavity and producing a bubbling sound at the orifice, is described as *metallic tinkling*. It is also thought to be due to the dropping of liquid into an accumulation of fluid at the base of the pneumothorax.

Voice-sounds, like breath-sounds, are louder over the laryngeal, tracheal, and bronchial regions. When the voice seems very close and loud to the ear placed over other regions (*pectoriloquy*, *bronchophony*), it indicates increased power of conduction,—*i.e.*, consolidation of lung-tissue.

If the tremor from the vibration of the vocal cords in speaking (*vocal fremitus*) is transmitted with increased distinctness to the hands placed on the surface of the thorax, it has the same significance. If it is absent, it usually indicates the interposition of some relatively non-conducting substance, as air (*pneumothorax*), or pus (*empyema*), or blood (*hæmothorax*).

Percussion-sounds vary with the region and the condition of the lungs and pleuræ. Normally, during quiet breathing, the resonance is increasingly clear from the supraclavicular region downward over the front of the chest to about the fifth rib on the right side—where the pulmonary tissue begins to decrease in thickness on account of the presence of the liver—and to the sixth rib on the left side. It is less above the clavicle and over it, on account of the comparatively small amount of lung-tissue in the apices; and over the upper part of the back, on account of the interposition of the scapulæ and of thick muscular masses. It becomes *diminished* in the presence of moderate effusion, as in œdema; *dull* if there is consolidation of lung-tissue; and is *absent* (flat) if there is either plastic exudate or fluid effusion in the pleural cavity. In pneumothorax, or over a cavity in the pulmonary tissue, especially if it is superficial, the percussion-note is *tympanitic*.

Injuries.—*Contusions* of the lung may occur without fracture of the bones of the thorax or obvious lesion of the parietes. They are thought to be due to suddenly applied elastic compression when—the glottis being closed—the lung or the lung and pleura are ruptured as one may burst an inflated paper bag between the hands.

The consequences are *interlobular emphysema*, the air having escaped from the ruptured air-cells into the connective-tissue spaces of the lung (*vide infra*); *general emphysema*, the air reaching the subcutaneous cellular tissue of the neck and trunk through a ruptured pleura, or, the pleura being unbroken, passing from the root of the lung into the mediastinum and thence to the base of the neck; *pneumo-*

thorax, the air entering the pleural cavity ; in traumatic interlobular emphysema, or pneumothorax, the chest on the affected side will be hyper-resonant, the vesicular murmur will be feeble or absent, and in the latter there may be amphoric breathing and—if there is a coincident effusion—metallic tinkling ; *hæmoptysis*, not an invariable symptom in either these injuries or lacerations by fractured ribs, probably because they are usually on the external lung surface and remote from the larger bronchi (Bennett); *hæmothorax*, indicated by percussion dulness gradually extending upward, by weakness or absence of respiratory murmur, by bronchial breathing over the compressed lung, and by absence of vocal fremitus.

Penetrating wounds of the lung will have many of these signs plus the escape of blood from the external wound. In the absence of hæmoptysis, the possibility of a wound of the costal pleura and of an intercostal or internal mammary artery causing hæmothorax, dyspnœa (from pressure), and hemorrhage, apparently influenced by respiration, should be borne in mind. Wounds of the pleura without involvement of the lungs are rare, the visceral pleura being closely adherent to the lung surface and the two pleural layers in close contact with each other. At the base of the pleura, where a potential cavity (page 1859)—*costo-phrenic sinus*—exists between the costal and diaphragmatic layers, a wound could penetrate both layers and the diaphragm and open the abdominal cavity and involve the liver or spleen (page 1788) without implicating the lung, which even in forced inspiration does not descend to the bottom of this sinus. Wounds of the pleura are apt to be followed by pneumothorax and by collapse of the lung, which is partly driven back towards its root and the vertebral column by the atmospheric pressure from without, and partly drawn there by its own elasticity even when the pressure within and without is equal. In operations for empyema this collapse of the lung may take place, but is infrequent because the pulmonary tissue has often already undergone considerable compression, and because the atmospheric pressure is resisted by preformed pleural adhesions.

General emphysema is often associated with wounds of the lungs and pleura. It may be due to (*a*) escape of air from a pneumothorax into the subcutaneous tissue during respiratory movements, or (*b*) escape of air direct from injured lung-tissue when pleural adhesions about the wound prevent the formation of a pneumothorax. Its occasional occurrence in laceration of the lung without external wound and without involvement of the pleura has been explained (*vide supra*). It may follow a non-penetrating wound of the chest if the opening happens to be valvular, so that the air drawn in during respiratory movements cannot make its exit by the same channel.

Pneumocele—hernia of the lung—is rare as a result of thoracic wounds because the elasticity of the lung-tissue and atmospheric pressure tend to cause collapse and retraction of the lung rather than protrusion. When it is primary it therefore follows (*a*) a limited and oblique wound through which air cannot freely enter the pleural cavity, although the egress of the lung under the pressure of muscular effort or the strain of coughing is unopposed ; or (*b*) a very large wound when the lung escapes at the moment of injury (Bennett). Treves says that these recent herniæ are most common at the anterior part of the chest where the lungs are most movable, and that the injuries that cause them are often associated at the time with violent respiratory efforts.

Pneumocele is more apt to follow the rare wounds that divide only the costal pleura, as a wound of the lung itself tends to the production of a pneumothorax—which would lead to collapse of the lung—and instantly lessens the pressure of air contained in the lungs and trachea, one of the forces favoring protrusion.

Diseases of the pleuræ and lungs can here be very briefly summarized only with reference to the anatomical factors.

Pleurisy is at first attended by a "friction-sound" due to the roughening of the opposed surfaces of the visceral and parietal pleuræ by fibrinous exudate. Later it may be lost by reason of (*a*) the temporary disappearance of the roughness, (*b*) the formation of adhesions between the surfaces, or (*c*) their separation by effusion. It is lost momentarily when the patient holds his breath, which will serve to differentiate it from a pericardial friction-sound. As the costal pleura, the intercostal

muscles, and the abdominal muscles are all supplied by the lower intercostal nerves, the respiratory movements on the affected side are painful and are therefore greatly limited. Accordingly there will be hurried, shallow breathing with a weak vesicular murmur on the affected side and exaggerated respiratory sounds on the opposite side. Pain and tenderness in the epigastrium may result from implication of the trunks of the lower intercostal nerves when the pleurisy is near the base of the chest. When it is higher the pain may be felt in the axilla and down the inner side of the arm from involvement of the intercosto-humeral nerve, or in the skin over the seat of disease through the lateral cutaneous branches of the upper intercostals (Hilton). In diaphragmatic pleurisy the pain may be intensified by pressure over the point of insertion of the diaphragm into the tenth rib (Osler).

Pleural effusion (*hydrothorax*, *empyema*), in addition to the signs already described (*vide supra*), causes, when it is of sufficient amount, additional symptoms, as bulging of the side of the chest with obliteration of the intercostal spaces, distention of the net-work of superficial veins (from pressure on the vena cava or greater azygos vein), and displacement of other viscera. If the fluid occupies the left pleura, as its weight depresses the diaphragm, the pericardium, which is attached to the central tendon, descends also, and with it the apex of the heart. At the same time the heart is pushed towards the right so that the apex beat may be felt in the epigastrium (Owen).

An empyema may *point* and discharge itself spontaneously, in which case it often does so at about the fifth interspace just beneath and external to the chondro-costal junction (Marshall). At this place the chest-wall is exceptionally thin, as the region is internal to the origin of the serratus magnus, external to the insertion of the rectus, and above the origin of the external oblique (McLachlan).

Evacuation of the fluid may be effected by paracentesis—in pleurisy with serous effusion—through the sixth or seventh intercostal space in the mid-axillary line, or through the eighth or ninth space just anterior to the angle of the scapula. The same regions are selected for *thoracotomy*—incision and drainage—in empyema. The former site is usually preferred for anatomical reasons already given (page 170).

Pneumonia is often limited to one lobe of a lung, usually the lower. The fissure between the two lobes of the narrower left lung runs from the third rib behind, or from about the third dorsal spinous process or the inner end of the spine of the scapula, to the base in front. The fissure between the two lobes of the right lung begins at about the same level behind and extends to the base of the lung anteriorly. Where it crosses the posterior axillary line a second fissure springs from it which passes horizontally forward to the fourth chondro-costal junction making the middle lobe. Both lower lobes are posterior to the anterior lobes, and on both sides the fissures run from the level of the inner end of the spine of the scapula behind to the base in front. Therefore the dulness, crepitant râles, bronchial breathing, and increased vocal fremitus of a lobar pneumonia affecting the base would often be below that line posteriorly and would be less marked in front; while the flatness, prolonged expiration, and other physical signs of a tuberculous infection (which affects by preference the upper lobe) would be above the spine of the scapula posteriorly, and lower would be more marked anteriorly.

The relations of the lungs to the thoracic walls have been described in detail (page 1855).

The congestion and œdema which precede the so-called "hypostatic pneumonia" are very apt to begin in the thick lower and posterior portions of the lower lobes in weak or aged persons kept long in the supine position.

Tuberculous infection of the lungs is found oftenest in the apices, probably because of the relatively defective expansion in that region which exists in all persons, and particularly in those of the so-called phthisical type, with round shoulders, long necks (page 143), and flat chests; possibly also because of the greater exposure to changes of external temperature; and perhaps somewhat owing to the short distance intervening between the outside atmosphere and the ultimate bronchioles where tuberculous pulmonary disease usually has its inception.

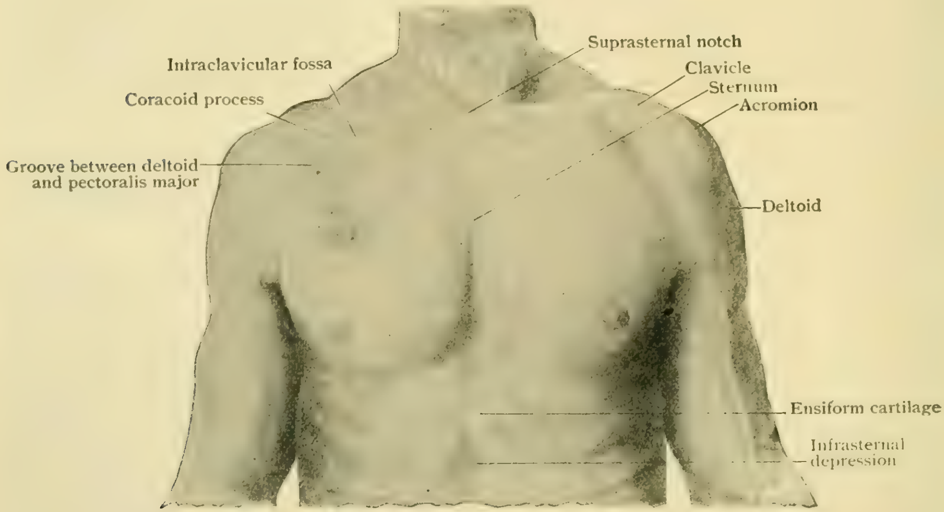
The physical signs are those indicating consolidation followed by softening or the formation of a cavity (*vide supra*).

Surface Landmarks of Thorax.—The most important of the bony points have already been described in connection with the spine, thorax, clavicle, and scapula. The relations of the thoracic viscera to the surface have likewise been given (page 1855).

Inspection or palpation of the front of the chest will show (*a*) the oblique elevations of the ribs and the intercostal depressions ; (*b*) the curved arch of the costal cartilages ; (*c*) the sternal groove ; (*d*) the angulus Ludovici ; (*e*) the infrasternal depression ; (*f*) the lower border of the great pectoral muscle ; (*g*) the digitations of the serratus magnus from the fifth to the eighth rib ; (*h*) the nipple (pages 168, 170, 171).

The infraclavicular fossa, the coracoid process, and the pectoral deltoid groove have been described in connection with the muscles and fasciæ of the shoulder (page 579).

FIG. 1590.



Surface landmarks of the anterior wall of the thorax.

On the posterior surface of the thorax the most useful landmarks that may be seen or felt are (*a*) the spine, acromion, vertebral edge and inferior angle of the scapula (pages 255, 256) ; (*b*) the spines of the dorsal vertebræ (page 148) ; (*c*) the median spinal or dorso-lumbar furrow, the groove between the erector spinæ masses overlaid by the trapezius above and by the latissimus dorsi below ; (*d*) the depression at the inner end of the scapular spine indicating the tendinous insertion of the lower fibres of the trapezius, the level of the third intercostal space, and a portion of the right bronchus ; (*e*) a slight groove passing upward and outward over the erector spinæ elevation from one of the lowest dorsal spines to this depression and marking the lower edge of the trapezius (Quain).

The landmarks of the ilio-costal space and lumbo-sacral region are sufficiently described on pages 148, 349.

THE URO-GENITAL SYSTEM.

The uro-genital system comprises two groups of organs, the urinary and the generative; the former serves for the elaboration and removal of the chief excretory fluid, the urine, and the latter provides for the formation and liberation of the products of the sexual glands. The primary relations between these sets of organs, as seen in the lowest vertebrates, are so intimate that the excretory duct of the primitive kidney may also transmit the sexual cells, both groups of organs being inseparably united. In the higher vertebrates the primary relations are suggested by only temporary conditions in the embryo, since with the development of a definite kidney differentiation and separation take place until the urinary and generative organs constitute independent apparatuses except at their terminal segment, where they are more or less blended in the external organs of generation. After serving for a time as the functionating excretory organ of the fœtus, parts of the Wolffian body and its duct become transformed into the ducts of the male sexual gland. In the female analogous canals, represented by the oviducts, uterus, and vagina, are not derived from the Wolffian duct, but from an additional tube, the Müllerian duct, which, however, is closely related to the primary canal of the fœtal excretory organ.

THE URINARY ORGANS.

These include the *kidneys*, the glands which secrete the urine, the *ureters*, the canals which receive the urine and convey it from the kidneys to the *bladder*, the receptacle in which the urine is temporarily stored, and the *urethra*, the passage through which the urine is discharged.

THE KIDNEYS.

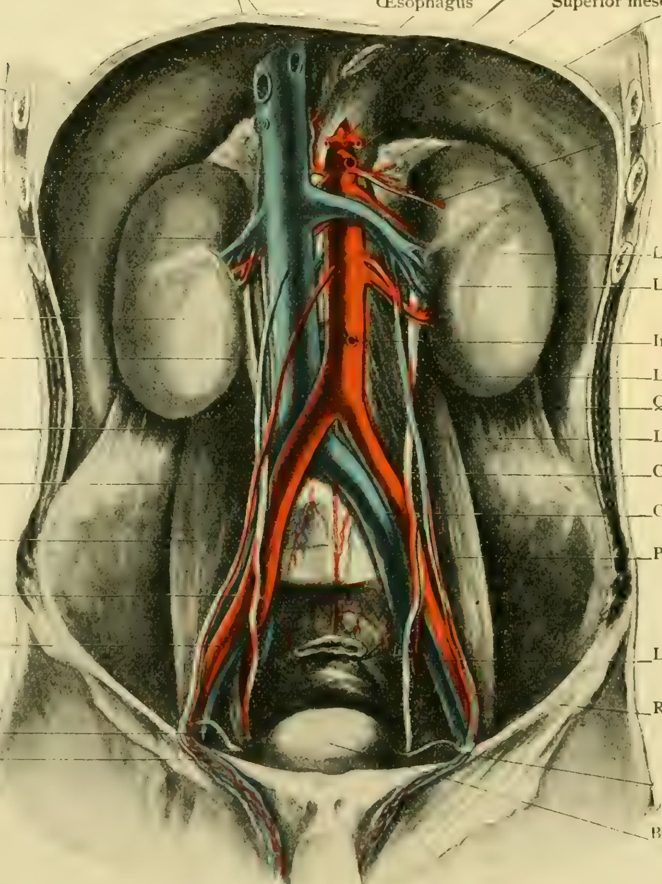
The kidneys (**renes**) are two flattened ovoid glands of peculiar form, described as bean-shaped, deeply placed within the abdominal cavity against its posterior wall and the diaphragm, one on either side of the lumbar spine. They are invested in a distinct, although thin, smooth, fibrous *capsule* (**tunica fibrosa**) and lie behind the peritoneum, surrounded by loose areolar tissue, which usually contains considerable fat (**tunica adiposa**). This fat is particularly conspicuous along the convex lateral margin and about the lower pole of the kidney and is least abundant around the upper end and over the anterior surface. The fresh adult organ, of a brownish-red color, weighs about 130 gm. (4½ oz.) in the male, slightly less in the female, and measures about 11.5 cm. (4½ in.) in length, 6 cm. (2½ in.) in width, and 3.5 cm. (1½ in.) in thickness. The left kidney is usually somewhat longer, narrower, and thicker, and slightly heavier than the right. Individual variations, especially as to length, are responsible in some cases for organs unusually long (15 cm.), in others for those relatively short.

Each kidney presents two **surfaces**, a convex *anterior* or visceral, when the organ is in place directed forward and outward, and a *posterior* or parietal, somewhat flattened and looking backward and inward; two rounded ends, or **poles**, of which the upper is usually the blunter and bulkier; and two **margins**, the *external*, marking the convex lateral outline of the organ, and the straighter *internal*. The latter is interrupted by a slit-like opening, the *hilum* (**hilus renalis**), bounded by rounded edges, which leads into a more extended but narrow space, the *sinus* (**sinus renalis**), enclosed by the surrounding renal tissue. The capsule is continued from the exterior of the kidney through the hilum into the sinus, which it partly lines. In addition to the blood-vessels, lymphatics, and nerves passing to and from the kidney through the hilum, the sinus contains the expanded upper end of the renal duct

or ureter, which also emerges at the hilum. The interspaces between these structures are filled with loose areolar tissue, in which lie accumulations of fat continuous with the perirenal tunica adiposa.

Position.—The kidneys lie behind the peritoneum, embedded within the subperitoneal tissue, so placed against the side of the vertebral column and the posterior abdominal wall that they occupy an oblique plane, their anterior surfaces looking forward and outward. The long axes of the organs are not parallel, but oblique to the spine, in consequence of which disposition the upper ends of the two organs are closer (8.5 cm.) than the lower extremities (11 cm.), the planes of the inner margins

FIG. 1591.



Dissection of abdomen, showing kidneys in position and course and relations of ureters.

being anterior to those of the external. The greater part of both kidneys lies within the epigastric region, but their outer margins reach within the hypochondriac areas and their lower ends ordinarily encroach to a limited and variable extent upon the umbilical and lumbar regions. The intersection of the plane of the transverse infracostal line and that of the vertical Poupart line usually passes through the lower pole of the kidney, falling, as a rule, somewhat higher in the right than in the left organ.

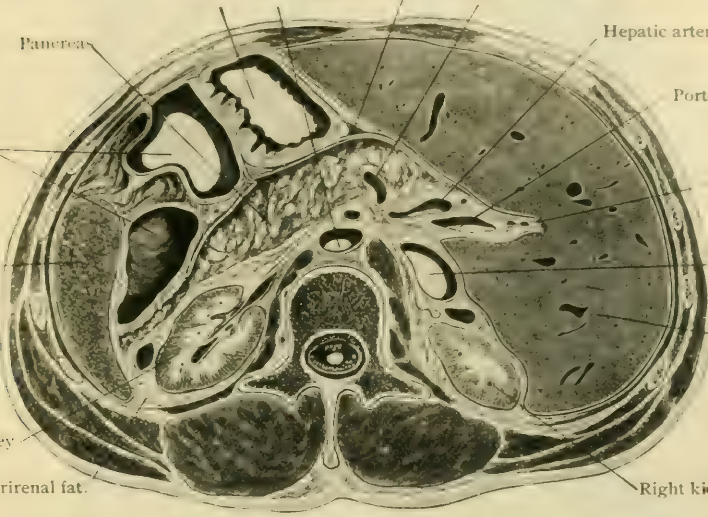
Approximately the kidneys may be said to lie opposite the last thoracic and the upper two lumbar vertebræ, reaching to within from 2.5–3.5 cm. (1–1½ in.) of the highest part of the iliac crest. The exact level of the kidneys, however, is subject

to considerable individual variation, as well as usually differing on the two sides in the same subject. The right organ commonly lies somewhat lower than the left, in consequence chiefly of the greater permanent volume of the right lobe of the liver. Not infrequently the kidneys occupy the same level, and in exceptional cases the ordinary relations may be reversed, the right lying a trifle higher than the left.

Addison[1] found that in 30 per cent. of the subjects examined by him the right kidney lay as high or higher than the left. According to Helm,[2] in women the kidneys lie, as a rule, about one-half of a lumbar vertebra lower than in men, this difference depending upon the smaller size of the vertebræ and the greater curvature of the lumbar spine in the female subject.

As a rule, the **right kidney** extends from the upper border of the last thoracic to the middle of the third lumbar vertebra, or somewhat below the lower border of the third lumbar transverse process. While always obliquely crossed by the twelfth rib, the outer margin of the right kidney usually falls short of the eleventh rib.

FIG. 1592.



Cross-section of formalin-hardened body at level of first lumbar vertebra.

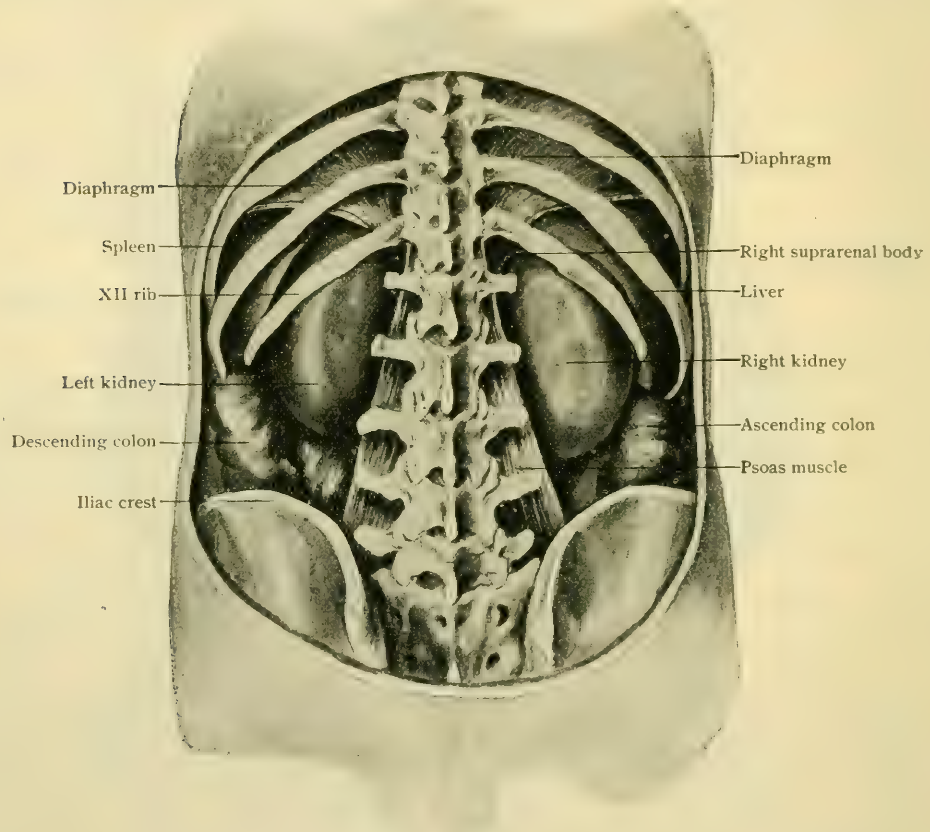
Since the **left kidney** usually lies from 1.5–2 cm. higher than the right, its upper pole is opposite the lower half of the eleventh thoracic vertebra, its lower level being opposite the lower border of the second lumbar vertebra and the third transverse process. Its outer margin may reach, or be crossed by, the eleventh rib; the costal relations are, however, variable and influenced by the obliquity of the ribs, which is greater when the ribs are well developed than when they are rudimentary. The kidneys in young children in general lie somewhat lower than in later life.

Fixation.—Although possessed of mobility to a limited degree,—slight depression and elevation probably normally accompanying respiratory movements,—the kidneys have a fairly fixed position. The maintenance of the latter has been variously ascribed to the support afforded by the peritoneum, the perirenal connective tissue and fat, the blood-vessels, and the surrounding organs, all of which during life may contribute to this end. Gerota, however,[3] has shown that, apart from the blood-vessels and, especially in children, the suprarenal bodies, the peritoneum and adjacent organs may be removed without materially lessening the fixation of the kidneys, the latter receiving support particularly from their peculiar and intimate relations with the subperitoneal tissue. This, in the vicinity of the kidney,

[1] Journal of Anatomy and Physiology, vol. xxxv., 1901.
[2] Anatom. Anzeiger, Bd. xi., 1896.
[3] Archiv f. Anat. und Entwick., 1895.

assumes the character of a distinct fascia (fascia renalis), which at the outer border of the organ splits into an anterior and a posterior layer. The former passes in front of the kidney, renal vessels, and ureter, and, crossing the great prevertebral vascular trunks, joins the corresponding layer of the opposite side. Traced upward, the anterior layer covers the suprarenal body, above this organ fusing with the posterior layer of the renal fascia. The latter passes behind the kidney, over the fascia covering the transversalis, quadratus, and psoas, as far as the inner border of the last muscle, along which it becomes attached to the spine. The posterior layer extends upward behind the suprarenal body, which, in conjunction with the anterior layer, is completely invested on all sides except below, where it lies against the kidney, to

FIG. 1593.



Posterior aspect of kidneys *in situ* in formalin subject; portion of posterior body-wall has been removed, as have been also parts of pleural sacs and diaphragm.

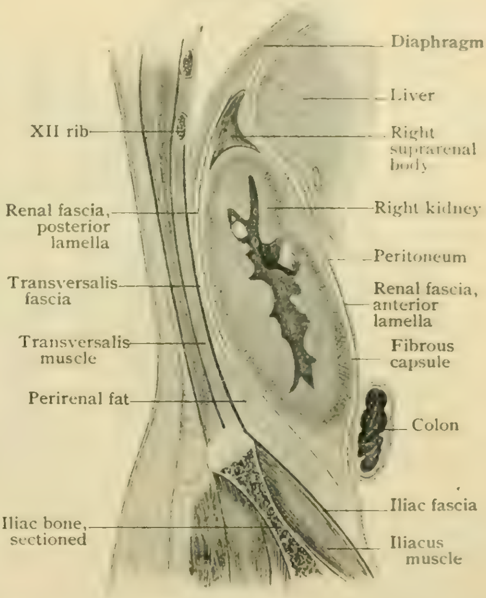
the support of which organ it materially contributes. Although everywhere separated from the fibrous tunic of the kidney by the intervening layer of fat (*tunica adiposa*), the renal fascia is attached to the renal capsule proper by bands of connective tissue, which are especially strong at the lower pole, thus directly affording support to the organ. Behind, the posterior layer of the renal fascia is likewise attached to the transversalis fascia by means of areolar tissue, between the connecting bands of which a variable amount of fat is usually present. Above, beyond the suprarenal body, the renal fascia fades away over the diaphragm; below, it passes into and is lost within the fatty subperitoneal tissue of the iliac fossa.

The fixation of the left kidney is firmer than that of the right, greater security being gained for the left organ in consequence of its more extensive relations to the

fusion which takes place during the development (page 1704) of the large intestine between the original parietal peritoneum and that covering the applied surface of the primary mesentery of the descending colon; in consequence, the left kidney is invested anteriorly with a subperitoneal layer of exceptional strength. When, for various reasons, the tonicity of the tissues supporting the kidney becomes impaired and these structures become abnormally lengthened, the organ may acquire undue mobility and suffer displacement.

Relations.—The position of the kidneys being wholly retroperitoneal, the **posterior relations** of both organs are chiefly muscular, since they lie closely applied to the diaphragm, psoas magnus, quadratus lumborum, and the posterior aponeurosis of the transversalis, the parietal fascia and perirenal areolar tissue alone intervening. The inequalities in the supporting structures produce corresponding modelling of the opposed renal surfaces, which is clearly distinguishable on organs hardened *in situ*. In specimens hardened in formalin, the psoas area appears as a narrow, slightly depressed tract along the inner border; an adjoining broader band marks the area for the quadratus lumborum, beyond which the outer part of the posterior surface rests upon the transversalis aponeurosis. The crescentic diaphragmatic area crosses the upper pole, the inner limb of the crescent marking the contact with the crus. In organs hardened in the recumbent posture, conspicuous and probably exaggerated indentations show the former position of the transverse processes of the second and third lumbar vertebræ. An oblique, shallow furrow crossing the kidney from the upper pole outward, usually locates the course of the twelfth rib. In connection with the posterior relations of the kidneys, it is important to recall the inferior limits of the pleural sacs (page 1859), which, where they cross the twelfth rib, may descend as low as the level of the first lumbar transverse process and therefore cover the upper part of the kidneys.

FIG. 1594.



Diagrammatic longitudinal section, showing relations of supporting tissue to right kidney. (*Gerota.*)

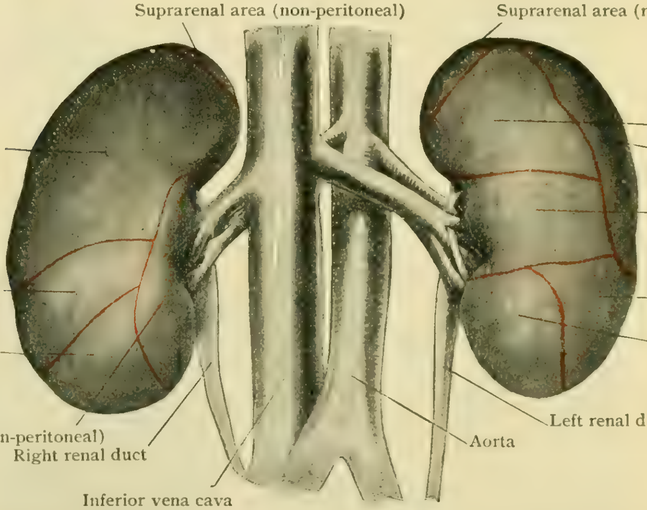
The **anterior relations of the kidneys** differ on the two sides, not only as to the viscera concerned, but also in the manner of their contact and the consequent extent of the renal peritoneal investment. Primarily the entire visceral surfaces of the kidneys are covered by serous membrane; later this investment becomes only partial, in consequence of the permanent attachment which certain organs, as the pancreas, duodenum, and colon, obtain. When these viscera undergo the backward displacement incident to acquiring their final location, they are pressed against the abdominal wall and the kidneys, to which they become attached by areolar tissue, since the intervening opposed peritoneal surfaces lose their serous character. Where the organs touching the kidneys remain covered with peritoneum, the renal areas of contact retain the original serous investment.

The **right kidney** is in relation with the corresponding suprarenal body, the liver, the duodenum, the hepatic flexure of the colon, and, to a limited extent, usually the small intestine. The right suprarenal body covers the upper pole and adjacent part of the inner border of the kidney, the surface of contact being devoid of peritoneum, since the organs are closely connected by areolar tissue. The liver covers the larger part of the anterior surface and outer border of the kidney, which models the hepatic tissue as the conspicuous renal impression seen on the inferior surface of the organ. Both the liver and the kidney are invested by serous membrane, and are, therefore,

separated by an extension of the greater sac of the peritoneum. The second part of the duodenum overlies the hilum and the inner renal border, the non-peritoneal area being of uncertain extent in consequence of the variations in the position of this part of the intestinal tube. Although covering usually about the middle two-fourths of the median border, the duodenal area may embrace the entire inner third or more of the anterior surface of the kidney, extending from the extreme upper to the lower pole; or, on the contrary, the duodenum may touch the kidney only near its lower pole. The hepatic flexure occupies a triangular area, external to the adjoining duodenal one and also non-peritoneal, which includes the outer and lower third, more or less, of the anterior surface of the kidney. The extent and form of the surfaces of contact between the kidney, colon, and duodenum are very variable; when large they may cover the entire lower half of the kidney, or when less extensive they may leave uncovered the lower pole. In the latter case coils of the small intestine often occupy this area, which is covered with peritoneum.

The **left kidney** is in relation with the corresponding suprarenal body, the spleen, the stomach, the pancreas, the splenic flexure of the colon, and the small intestine. The suprarenal body lies upon the median side of the upper pole, attached

FIG. 1595.



Anterior surface of kidneys of formalin-hardened subject, showing visceral areas, blood-vessels, and renal ducts.

by areolar tissue; its area is therefore non-serous. The upper two-thirds of the outer border and the adjacent part of the anterior surface of the kidney are covered by the spleen, the peritoneum intervening, except within the narrow attachment of the layers of the lieno-renal ligament. Below the splenic area the kidney is covered to a variable extent by the splenic flexure of the colon, this non-peritoneal area usually including the outer half of the lower pole. The pancreas lies in front of the hilum and approximately the middle third of the kidney, frequently reaching as far as the outer border. Above this non-peritoneal area, between the latter and the suprarenal and splenic surfaces, lies the small triangular serous area which the stomach touches, while below the pancreatic zone, internal to that for the splenic flexure, the kidney presents a triangular peritoneal area over which the coils of the jejunum glide.

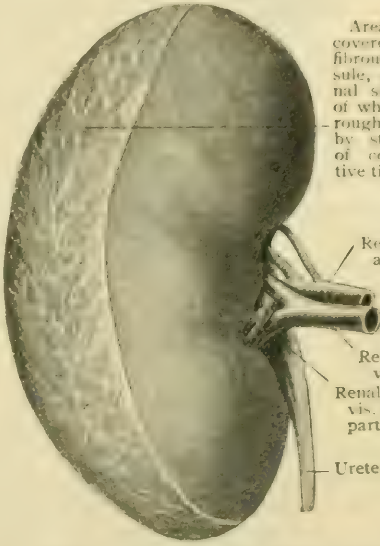
From the foregoing it is evident that each kidney rests within a depression, the "renal fossa," formed by the structures with which it comes into contact above, behind, at the sides, and below. The fossæ are deeper and narrower in the male than in the female, owing chiefly to the greater development of the muscles against which the kidneys lie.

The Renal Sinus.—The longitudinal, slit-like hilum, occupying somewhat less than the middle third of the inner border of the kidney, opens into a more extensive but shallow C-shaped space, the renal sinus, which, surrounded by the kidney-tissue,

takes in approximately the median half of the interior of the organ. The greatest dimension of the sinus corresponds with the long axis of the kidney, the shortest with the distance between the anterior and posterior walls. The space—most extended vertically—is compressed from before backward, while its greatest depth (2.5–3.5 cm.) is just above the upper border of the hilum. The sinus is occupied in large measure by the dilated upper end of the ureter, the *renal pelvis*, and its subdivisions, the *calyces*; the remaining space accommodates the blood-vessels, lymphatics, and nerves that pass through the hilum and the intervening cushion of areolar and adipose tissue continuous with the perirenal fatty capsule. The fibrous capsule of the kidney covers the rounded lips of the hilum and is continued into the sinus, to which it furnishes a partial lining.

In contrast to the even external surface of the kidney, the walls of the sinus are beset with conical elevations, the *renal papillæ*, which are well seen, however, only after removal of the contents and the fibrous lining of the sinus. The papillæ mark the apices of the pyramidal masses of kidney-tissue of which the organ is composed. The individual cones, from 7 to 10 mm. in height, are in many instances somewhat compressed, so that their bases are elliptical in section instead of circular. Adjacent ones may undergo more or less complete fusion, the resulting compound papillæ being often grooved and irregular in form. Usually from eight to ten papillæ are present in each kidney, but their number varies greatly, as few as four and as many as eighteen having been observed (Henle). The walls of the sinus between the bases of the papillæ are broken up into elevations and depressed areas, the latter marking the localities at which the blood-vessels and nerves enter and leave the renal substance. The *apex* of each papilla is pierced by a number of minute openings, barely recognizable with the unaided eye, which mark the terminal orifices (**foramina papillaria**) of the uriniferous tubules from which the urine escapes from the renal tissue into the receptacles formed by the calyces which surround the papillæ and are attached to their bases. The number of uriniferous tubules opening at the apex of a single papilla—the field in which the pores open being the *area cribrosa*—varies with the size of the cone, from eighteen to twenty-four being the usual complement for a simple papilla. When the latter is compound and of large size, more than twice as many orifices may be present.

FIG. 1596.



Anterior surface of right kidney from which fibrous capsule has been partly removed; blood-vessels and renal duct are seen entering and emerging through hilum.

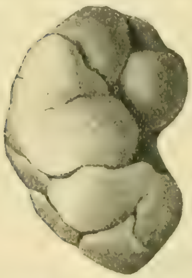
Architecture of the Kidney.—The entire organ—a conspicuous example of a compound tubular gland—is made up of a number of divisions which in the mature condition are so closely blended as to give little evidence of the striking lobulation marking the fœtal kidney. The external surface of the latter (Fig. 1597) is broken up by furrows into a number of irregular polygonal areas, each representing the base of a pyramidal mass of renal tissue, the kidney **lobe** or *renculus*, which, separated from its neighbors by an envelope of connective tissue, includes the entire thickness of the organ between its exterior and the sinus, a renal papilla being the apex. For a short time after birth the lobulation is evident, but later the demarcations gradually disappear from the surface, which becomes smooth, and the interlobular connective-tissue septa within the organ disappear, the pyramids alone indicating the original lobulation.

Although evidences of the latter occasionally persist in the adult human organ, the kidneys of many of the lower animals (reptiles, birds, ruminants, cetaceans, and certain carnivora) retain

the divisions in a more or less marked degree, the renal lobules of the aquatic mammals being unusually distinct. In some mammals (rodents, insectivora) the entire kidney corresponds to a single papilla, while in others (elephant, horse) no distinct papillæ exist.

On making a longitudinal section of the fresh kidney, from its convex border through the sinus, the papillæ will be seen to form the free apices of conical masses, the **renal pyramids**, the bases of which lie embedded within the darker surrounding kidney-substance composing the outer third of the organ. This peripheral zone, which appears darker and granular in contrast to the lighter and striated renal pyramids, constitutes the *cortex;* the **medulla** includes the conical areas formed by the pyramids and partially occupies the inner two-thirds of the thickness of the organ. The cortex contributes the bulk of the kidney, alone forming the entire surface, including the lips of the hilum, and receiving and surrounding the bases of the pyramids. The cortical tissue further penetrates for a variable distance between the pyramids, separating the latter and in places gaining the sinus. These interpyramidal extensions are the *renal columns*, or *columns of Bertin*, and consist of typical cortical substance. Since the branches of the renal blood-vessels lie within the interlobular connective tissue separating the primary divisions of the fœtal organ, these vessels never enter the kidney by passing into the papillæ, but always enter at the side of these. They therefore sink into the renal substance within the areas occupied by the renal columns, the surfaces of which directed towards the sinus are pitted by the vascular foramina. Within the sinus the blood-vessels surround the calyces with coarse net-works, entering and emerging from the renal substance through the orifices encircling the papillæ.

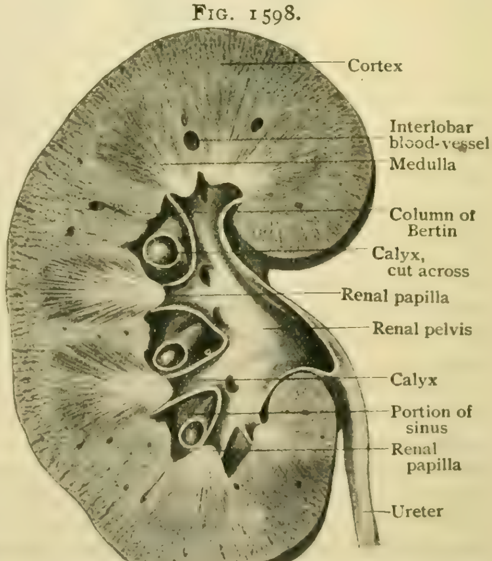
FIG. 1597.



Right kidney of new-born child, showing lobulation of surface.

On close inspection, preferably with the aid of a hand-glass, it will be seen that the **cortex,** including that within the renal columns, is not uniform, but is subdivided by narrow striated bands, wedge-shaped in outline and lighter in color, into radially disposed darker and lighter areas. The latter, consisting of groups of parallel tubules, are known as the *medullary rays* (**pars radiata**), since they are apparently due to prolongations of the medullary tissue. The darker tracts intervening between the medullary rays form the *labyrinth* (**pars convoluta**), and appear granular, owing to the tortuous character of the component tubules. The labyrinth is studded with bright red points marking the position of the vascular tufts or *glomeruli*, which are never present within the medullary rays or the renal pyramids, although found within the columns of Bertin.

FIG. 1598.



Longitudinal section of right kidney, showing relations of pelvis and its divisions to renal substance and to sinus.

On sectioning minutely injected organs, it will be observed that the larger radially coursing interlobular arteries, on gaining the boundary zone between the cortex and medulla, break up into smaller branches, some of which pass directly towards the surface, while others change their direction and assume an arched horizontal course, thus producing the impression of "arcades" at the base of the pyramids. The terminal twigs—"end-arteries," since anastomoses are wanting—run generally perpendicular to the exterior of the kidney and occupy the centre of the tracts separating the medullary rays. The latter, therefore, are the axes of

minute conical masses of renal substance, the *cortical lobules*, the bases of which lie at the surface and the apices within the pyramids of the medulla. From the foregoing it is evident that each renal pyramid corresponds to a group of cortical lobules, the tubules of which, on entering the medulla, become progressively less numerous but larger, in consequence of repeated juncture, until, as the wide excretory ducts, they end at the summit of the papilla. The relations of the pyramids to the papillæ are less simple than formerly recognized, since, instead of each of the latter embracing but one of the former, Maresch[1] has shown that a single papilla, as a rule, includes from two to four pyramids, which are blended into one conical mass culminating in the papillary apex.

FIG. 1599.

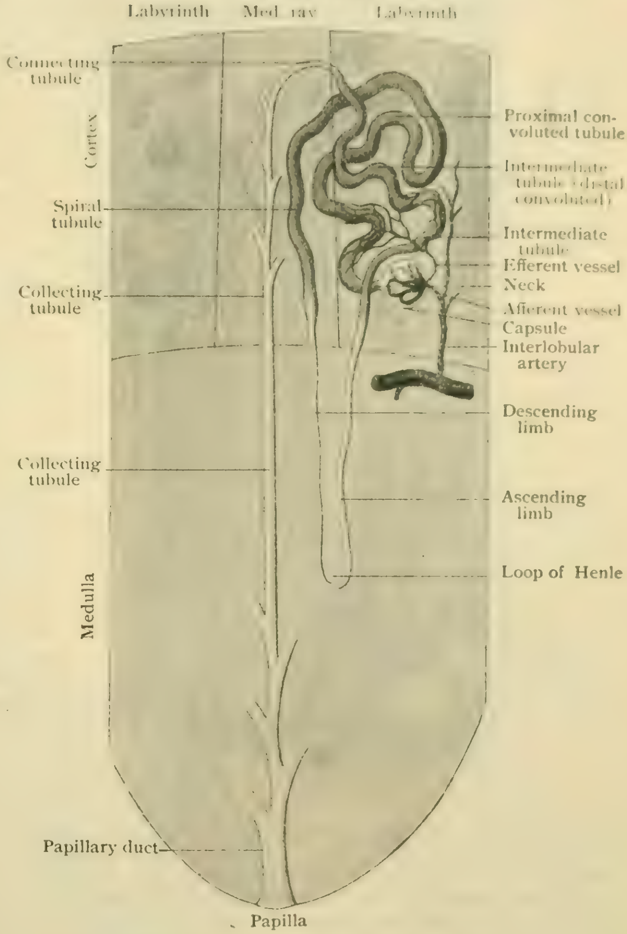


Diagram showing course of uriniferous tubule.

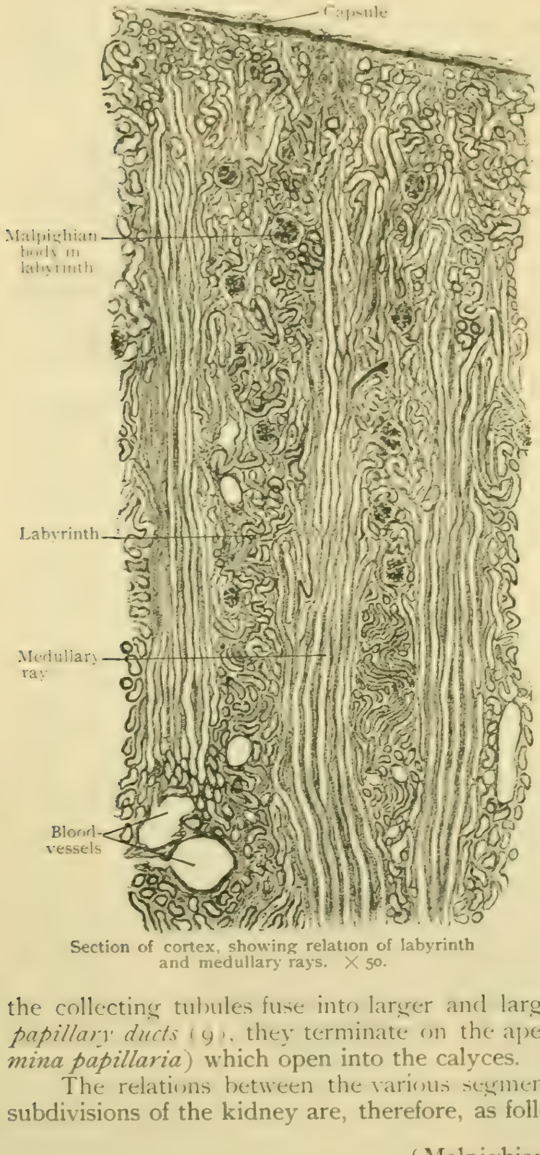
Structure of the Kidney. — The fundamental components of the vertebrate excretory organ, both in the fœtal and mature condition, include (1) a tuft of arterial vessels derived more or less directly from the aorta, (2) tubules lined with secretory epithelium, and (3) a duct for the conveyance of the excretory products. These constituents are represented in the kidney of man and the higher animals by (1) the glomerulus, (2) the convoluted uriniferous tubules, and (3) the collecting tubes, pelvis, and ureter. Since, in a general way, to the epithelium lining the tubules may be ascribed the function of taking from the circulation the more solid constituents of the urine, and to the glomerulus the secretion of its watery parts, obviously the most favorable arrangement to secure the removal of the excretory products is one insuring flushing of the entire tubule with the fluid secreted by the glomerulus. Such arrangement implies the location of the vascular tuft at the very beginning of the tubule,—a disposition which in fact is found in the kidneys of all higher animals. The number of the glomeruli, therefore, corresponds with that of the uriniferous tubules, each of which begins in close relation with the vascular tuft. The kidney-substance consists of an intricate but definitely arranged complex of uriniferous tubules, supported by the interstitial connective-tissue stroma, which have their commencement in the cortex and their termination at the apices of the papillæ, their intervening course being marked by many and conspicuous variations in the character, size, and direction of the tubules.

The **uriniferous tubule** begins as a greatly expanded blind extremity, the *capsule* (1), which surrounds the vascular tuft or *glomerulus*, the two together constituting the *Malpighian body*, which lies within the labyrinth. On leaving the Mal-

[1] Anatom. Anzeiger, Bd. xii., 1896.

pighian body the tubule becomes very tortuous and arches towards the free surface as the *proximal convoluted tubule* (2); this, after a course of considerable length, usually leaves the labyrinth and enters the medullary ray, which it traverses, somewhat reduced in diameter and slightly winding in course, as the *spiral tubule* (3) and passes into the medulla. Immediately upon gaining the latter, the tubule suffers marked decrease in size, penetrates the renal pyramid for a variable distance towards the papilla, then bends sharply upon itself and retraces its course to once more enter the labyrinth. Its excursion into the medulla includes the *descending limb* (4) and *ascending limb* (5) of the *loop of Henle.* The ascending limb—the longer and wider of the parallel limbs of the loop—rises within the labyrinth to the immediate vicinity of the corresponding Malpighian body, the neck of which it crosses, and then, after arching over the corpuscle, gives place to the *distal convoluted* or *intermediate tubule* (6), a segment which, marked by increased diameter and tortuosity, crosses the general course of the convoluted tubule and is succeeded by the narrower and arching *connecting tubule* (7). The latter enters the medullary ray and, joining with similar canals, forms the straight *collecting tubule* (8), which, progressively increasing in size by junction with others, traverses the remaining length of the medullary ray and enters the renal pyramid. Within the deeper part of the latter the collecting tubules fuse into larger and larger canals until, as the relatively wide *papillary ducts* (9), they terminate on the apex of the papilla at the orifices (*foramina papillaria*) which open into the calyces.

FIG. 1600.



Section of cortex, showing relation of labyrinth and medullary rays. × 50.

The relations between the various segments of the uriniferous tubules and the subdivisions of the kidney are, therefore, as follows :

CORTEX	Labyrinth	Malpighian body,—capsule and glomerulus Proximal convoluted tubule Ascending limb of Henle's loop Distal convoluted or intermediate tubule Connecting tubule (beginning)
	Medullary ray	Connecting tubule (termination) Spiral tubule Collecting tubule
MEDULLA		Descending limb and Ascending limb of Henle's loop Collecting tubule Papillary ducts

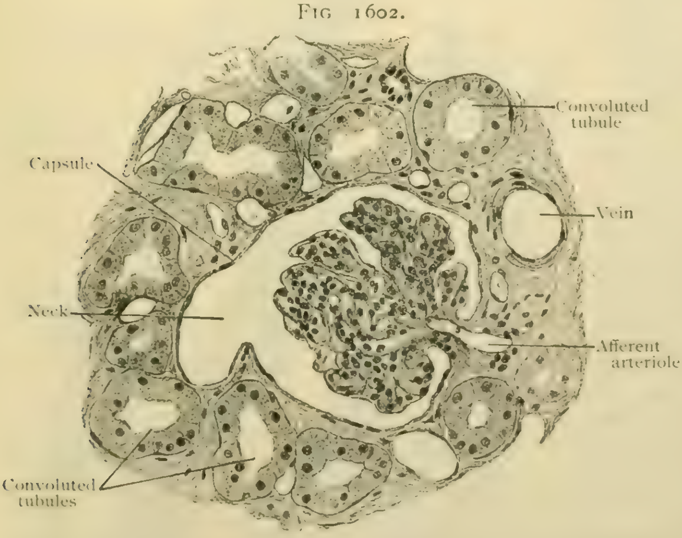
Although as a matter of convenience the entire canal, from its commencement in the Malpighian body to its termination on the papilla, has been described as the uriniferous tubule, both genetically and functionally two distinct parts must be recognized. These are the unbranched *uriniferous tubule proper*, which includes all divisions from the Malpighian body to the termination of the intermediate tubule, and the *duct-tube*, which, when traced from the papilla towards the cortex, undergoes repeated division until from a single stem the number of connecting tubules is sufficient to provide each uriniferous tubule proper with its own excretory canal.

FIG. 1601.

Injected glomerulus, showing afferent and efferent vessels and continuation into intertubular capillaries. × 250.

1. The Malpighian Body.—This structure, spherical in form and from .012–.020 mm. in diameter, consists of two parts, the *glomerulus* and the *capsule*. The former is an aggregaion of tortuous capillary blood-vessels into which break up the lateral terminal twigs given off from the arteries as these pass between the cortical lobules towards the free surface of the kidney. The lateral branches—very short, often arched, and only .002–.004 mm. in diameter—spring at varying angles from all sides of the interlobular arteriole and enter the Malpighian body as the *vas afferens*. On entering the glomerulus, the afferent vessel divides into from four to six twigs, each of which breaks up into capillaries. These may anastomose and form a vascular complex that may be filled from any branch; not infrequently, however, such communication does not exist, each terminal twig then giving rise to an isolated capillary territory, the entire glomerulus consisting of vascular lobules, each drained by its own radicle. Sooner or later all the channels of exit unite to form the single *vas efferens*, through which the blood from the entire glomerulus escapes. The efferent vessel as it emerges from the Malpighian body is close to the vas afferens, both usually lying on the side opposite to that occupied by the neck of the capsule from which the uriniferous tubule is continued. In consequence of the short course and manner of origin of the twigs from the interlobular arteries, the glomeruli are disposed in rows, somewhat like berries attached to a straight common stalk.

FIG. 1602.

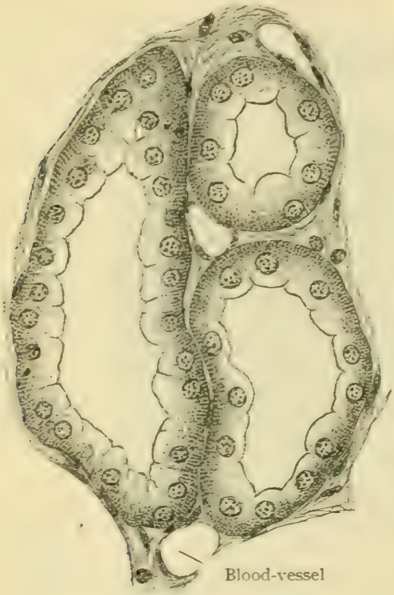


Section of renal cortex, showing details of Malpighian body; glomerulus is surrounded by capsule which passes into obliquely cut neck. × 200.

The *capsule of Bowman*, the dilated beginning of the uriniferous tubule, almost completely invests the glomerulus with a double layer derived from the wall of the tubule, which seemingly has suffered invagination by the vascular tuft. Such pushing in, however, is only

apparent, since the close relations of glomerulus and capsule result from the growth of the latter around the vascular tuft and not from invagination of the dilated tubule. The capsule consists of a distinct membrana propria and a lining composed of a single layer of flat, plate-like cells, the modified epithelium of the uriniferous tubule. In sections passing through the afferent vessel and the neck the lumen of the capsule appears crescentic in outline, since the space between its outer and inner walls is widest at the neck and reduced to a mere slit where the two layers are continuous around the narrow stalk traversed by the afferent and efferent vessels. The inner or "visceral" layer of the capsule, the thicker of the two, is firmly attached to the glomerulus by the delicate intervening connective tissue, the entire complex appearing rich in nuclei which belong to the epithelium of the capsule, the endothelium of the capillaries, and the connective-tissue cells.

FIG. 1603.

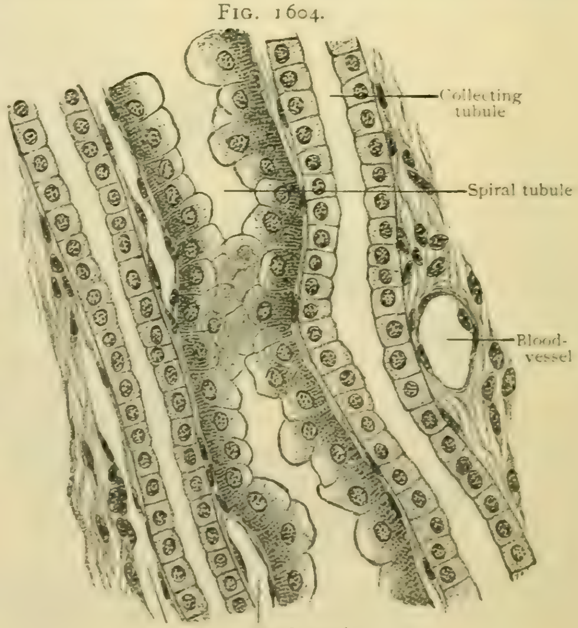


Convoluted tubules, cut transversely and obliquely, showing character of epithelial lining. × 40.

2. **The Proximal Convoluted Tubule.**—After undergoing the conspicuous constriction marking the *neck* of the capsule, the uriniferous tubule abruptly enlarges into the convoluted segment which forms approximately one-fifth of the length of the entire canal and has a diameter of from .040–.060 mm. In common with other parts of the tubule, its wall consists of a membrana propria, apparently structureless, but composed of a delicate reticulum and intervening homogeneous substance and a single layer of epithelial cells.

Although the histological details of the latter vary in different, but not constant, parts of the convoluted segment, the lining cells present certain characteristics, chief among which is the differentiation of the cytoplasm of the cells into a broader *outer* and a narrow *inner* zone. The former exhibits coarse radial striations, the so-called "rods," produced by rows of granules within the vertically disposed threads of spongioplasm (Rothstein) which occupy approximately the peripheral half of the cell extending from the membrana propria towards the inner zone. The latter, next the lumen, usually appears as a well-defined narrow border which, when successfully preserved, presents a fine vertical striation ("bristle border") that depends not upon rows of granules, as do the rods of the outer zone, but upon the disposition of the threads of the spongioplasm. In consequence of maceration and other post-mortem changes, the inner zone may undergo partial disintegration and break up into short hair-like rods which have been mistaken for cilia. Although the spherical nuclei (.005–.007 mm.) of the epithelium of the convoluted tubule are sharply defined, the demarcations between the individual cells are obscure and often wanting, the tubule being lined by a seemingly continuous nucleated layer or syncytium. The lumen is not uniform throughout the convoluted tubule, in some places being wide and in others reduced to mere clefts; these differences depend chiefly upon the varying height of the epithelial lining.

FIG. 1604.



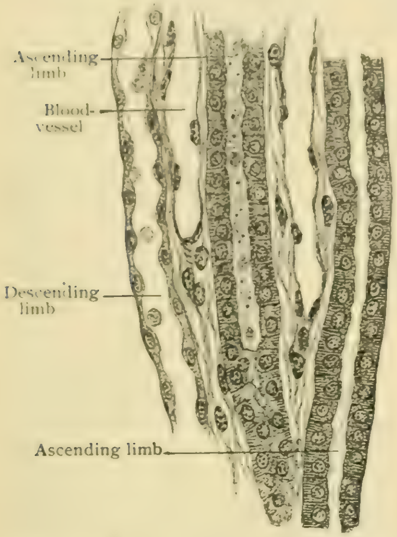
Portion of medullary ray, showing spiral and collecting tubules. × 400.

3. **The Spiral Tubule.**—Following the tortuous path of the convoluted tubule, the canal is usually continued into the medullary ray by a segment which, while comparatively straight, de-

scribes a wavy or spiral course in its descent to the pyramid. Thus, the spiral tubule of Schachowa, differs from the preceding in the gradual reduction of its diameter (.35–.040 mm.) and in the thickness of the epithelial lining, the cells of which, although retaining the general character of those of the convoluted tubule, exhibit a distinct demarcation from one another and a narrow homogeneous inner zone. The spiral tubules are distinguishable from the surrounding collecting tubules by the lighter sharply defined cuboidal lining cells of the latter. Just before passing into the medulla to become the descending limb of Henle's loop, the spiral tubule diminishes in width and in consequence ends as a canal of conical form.

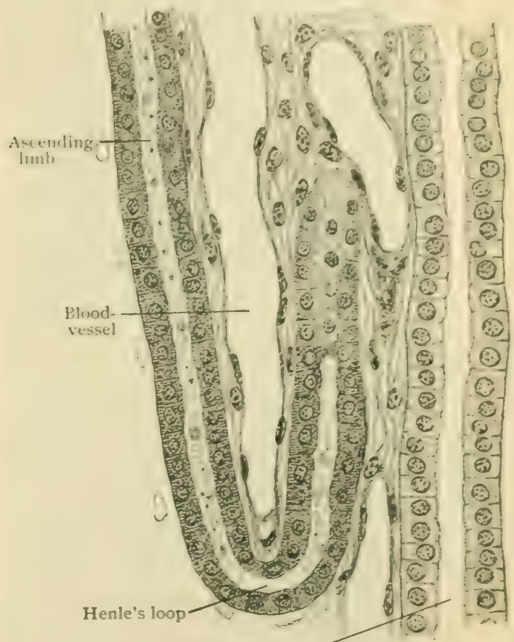
4. **The Loop of Henle.**—The *descending limb* of this U-like segment is distinguished not only by the conspicuous reduction in its diameter (.012–.015 mm.), being the narrowest part of the entire uriniferous tubule, but also by the altered character of its epithelium. The latter consists of low elements, so thin that the oval nuclei cause distinct elevations in the cells which project beyond the general level of the epithelium. Since the nuclei usually do not lie exactly opposite each other, the projections on one wall alternate with those of the other, in consequence of which disposition the lumen appears wavy and irregular, although not much reduced below the diameter of that of the preceding spiral segment and generous in proportion to the entire width of the tubule. The flattened cells consist of clear, slightly granular cytoplasm, in which is embedded a distinct elliptical nucleus of relatively large size.

FIG. 1605.



Longitudinal section of medulla, showing parts of limbs of Henle's loop. × 400.

FIG. 1606.



Longitudinal section of medulla passing through Henle's loop. × 400.

The *ascending limb* differs from the descending in its increased diameter (.024–.028 mm.), which depends upon sudden augmented thickness of the walls and not upon the width of the lumen, the darker and striated appearance of its epithelium, and its extension from the medulla into the cortex. The outlines of the individual lining cells are not sharply defined in well-preserved organs, although the readiness with which these elements undergo post-mortem change often results in their artificial separation. The cells are often irregular in height, the lumen, in consequence, varying and in places, especially within the cortex, being almost obliterated. The nuclei often occupy a clear area, and are separated by striations of unusual length. Although the cells exhibit a differentiation into an outer rodded zone, a finely striated inner border, as seen in the epithelium of the convoluted tubules, is wanting; where an inner zone is represented, it assumes a variable vesicular rather than a striated character. The length of the loop of Henle is influenced by the level of the corresponding Malpighian body within the cortex—the nearer the latter lies to the medulla the greater the descent of the loop towards the papilla, and *vice versa*, this relation probably depending upon the intimate association between the termination of the ascending limb and the Malpighian body. According to the reconstructions of Huber,[1]

[1] Amer. Journ. of Anatomy, vol. iv., Supplement, 1905.

on gaining the Malpighian corpuscle the ascending limb crosses the neck in close proximity to the glomerulus, with which it is connected by twigs from the vas efferens (Hamburger[1]), and then arches over the corpuscle to end in the succeeding convoluted tubule. The position of the sudden transition from the narrow into the wider tube of Henle's loop varies, the change exceptionally occurring after the turn is reached, sometimes within the loop itself, but most frequently within the descending limb a short distance above the loop.

5. **The Distal Convoluted Tubule.**—On gaining the level of the corresponding Malpighian body, the ascending limb gradually widens into the distal convoluted or intermediate tubule, a canal approximating the diameter (.040–.045 mm.) of the surrounding convoluted tubules, but differing from the latter in its wider lumen and in the character of its epithelium. This consists of well-defined cuboidal cells, with spherical nuclei, the cytoplasm of which, while granular, is comparatively clear and devoid of striations. The moderately tortuous path of the intermediate tubule is marked by a number of abrupt changes in direction, but in general lies for a time enclosed by the arch described by the corresponding convoluted segment (Schweiger-Seidel), which it finally crosses (Huber).

Fig. 1607.

Longitudinal section of renal medulla, showing Henle's loops and collecting tubules. × 45.

6. **The Connecting Tubule.**—This portion of the tubule (.023–.025 mm. in diameter) resembles the preceding segment in its clear epithelium, the lining cells, however, being lower, with a corresponding increased lumen. After a short and usually arched course, the connecting tubule enters the medullary ray and, uniting with similar canals, joins in forming the collecting tubule.

7. **The Collecting Tubule.**—This first lies within the medullary ray, where it forms the beginning of the system of straight duct-tubes that culminates in the canals opening upon the papilla, and then passes into the renal pyramid. During their course through the medullary ray the collecting tubules repeatedly unite to produce stems, which, while increasing four- or fivefold in diameter, are diminishing in number. In consequence of this fusion within the pyramid, the collecting tubules are disposed in groups (Fig. 1609), each of which corresponds to the tubules prolonged from a single medullary ray and is surrounded by the limbs of the loops of Henle. On entering the renal pyramid, the groups of collecting tubules at first are separated by the intervening bundles of straight blood-vessels (*vasa rectæ*) that are given off from the larger twigs within the boundary zone for the supply of the medulla. After passing to within about 5 mm. of the apex of the papilla, towards which they converge, the large collecting canals undergo repeated junction, increasing in diameter but rapidly diminishing in number, to form the wide papillary ducts. The epithelium lining the collecting tubules —the larger as well as the smaller—consists of clear cuboidal or low columnar cells, sharply defined from one another and provided with spherical nuclei. The light-colored cytoplasm and distinct demarcation of these elements render the collecting tubules conspicuous and their recognition easy.

8. **The Papillary Ducts.**—These, the final segments of the kidney tubules, number from ten to eighteen for each single papilla, at the apex of which they end. Each is formed by the junction of from ten to thirty of the larger collecting tubules (.050–.060 mm.) and attains a diameter of from .2–.3 mm. The lining epithelium is composed of conspicuous, clear columnar cells, about .020 mm. in height and one-third as much in width, which rest upon a distinct

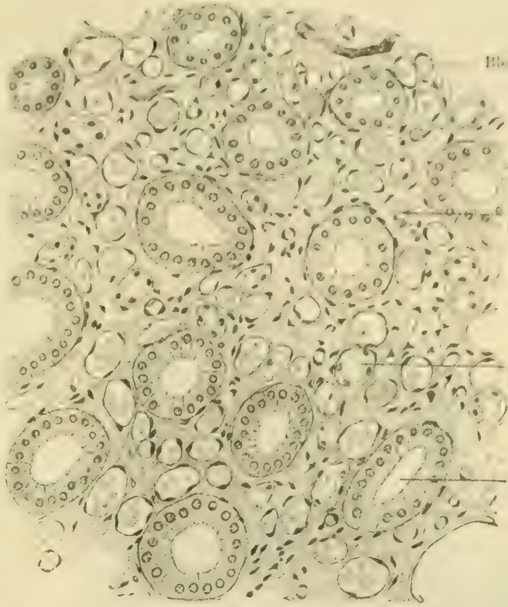
[1] Archiv f. Anat. u. Entwick., Suppl. Bd., 1890.

membrana propria almost as far as the termination of the canal. At this point the membrane fades away and the epithelium of the duct becomes continuous with that clothing the surface of the papilla and lining the pelvis of the kidney.

It is evident that the number of Malpighian bodies and uriniferous tubules proper is greatly in excess of the larger collecting tubes, each papillary duct representing the termination of an elaborate system of dividing canals as far as the connecting tubules, from which point the true uriniferous tubules complete their tortuous path without further subdivision.

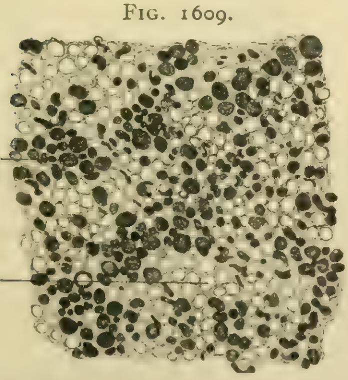
The Supporting Tissue. The interstitial stroma holding in place the tubules and the blood-vessels consists of a net-work of modified connective tissue, or reticulum, which has been shown by Mall to withstand pancreatic digestion and to form a continuous framework throughout the kidney. The stroma is most abundant along the paths of the interlobular and the larger blood-vessels, from the adventitia of which delicate trabeculæ extend in all directions to form the meshes lodging the tubules, smaller vessels, and capillaries. Within the cortex the supporting tissue is meagre, being best developed along the interlobular vessels and around the Malpighian bodies. According to Mall, the membrana propria of the tubules is resolvable into delicate net-works of reticulum directly continuous with the surrounding stroma, the general arrangement of which corresponds to the disposition of the tubules. Within the medulla the interstitial tissue is much more abundant than in the cortex, its amount increasing towards the apex of the papilla, in which location considerable tracts of comparatively coarse stroma-fibres separate the papillary ducts. At the surfaces of the divisions of the renal substance the interstitial tissue is continuous with the investing fibrous capsule, the interlobar septa, or the lining of the pelvis, as the case may be. Not only the blood-vessels, but likewise the nerve-trunks and the lymphatics are provided with sheaths of the renal stroma.

FIG. 1608.



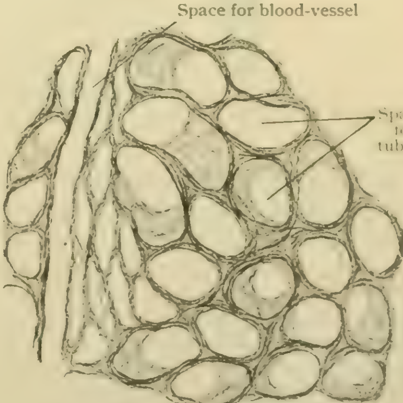
Section of medulla across renal pyramid, showing large collecting tubules, limbs of Henle's loops, blood-vessels, and stroma. × 130.

FIG. 1609.



Section across upper part of renal pyramid, showing groups of blood-vessels surrounded by uriniferous tubules. × 50.

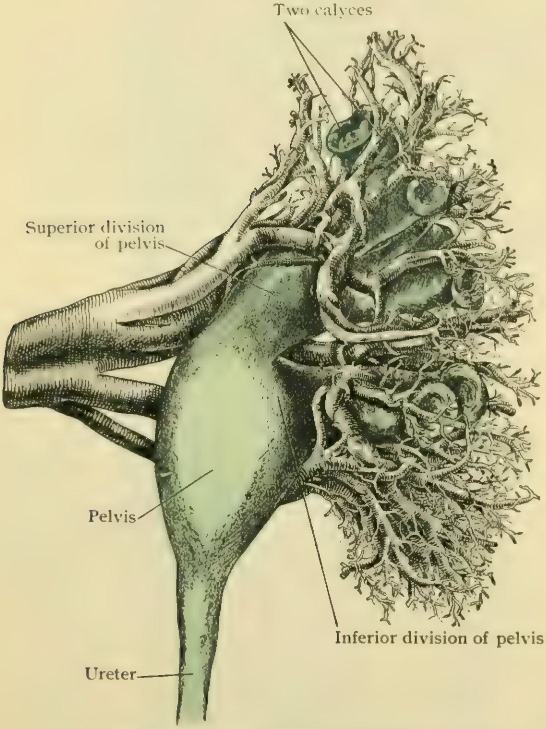
FIG. 1610.



Supporting stroma-tissue of kidney after pancreatic digestion; spaces lodged tubules and blood-vessels. × 110.

Blood-Vessels.—*Arteries.*—The renal arteries—usually one to each kidney, but not infrequently two, and in exceptional cases three or even four—are of unequal length, the right one being the longer in consequence of the parent stem, the aorta, lying to the left of the mid-line. Embedded within the subperitoneal tissue and covered by the renal fascia (page 1872), they pass laterally, accompanied and more or less masked by the renal veins, to the hilum of the kidney, during their course giving off small twigs to the capsula adiposa as well as to the suprarenal bodies. Just before entering the kidney, or within the hilum, the renal artery divides into an anterior (ventral) and a posterior (dorsal) branch, each of which embraces the pelvis and divides into four or five twigs that hug their respective wall of the sinus. Preparatory to entering the kidney, each twig breaks up into from three to five smaller divisions which enter the renal substance through the vascular foramina surrounding the papillæ. On entering, they pass along the sides of the papillæ, their course corresponding in position to the original tracts of connective tissue that separate the primary divisions of the fœtal kidney (page 1876); they are therefore appropriately designated *interlobar arteries.* The general expansion of the branches derived from the anterior and posterior arteries is parallel to the corresponding ventral and dorsal surfaces of the kidney; the intervening zone along the convex border of the organ, about 1 cm. on the posterior surface, contains few, if any, of the larger vessels and, in consequence, appears lighter in color. The vessels supplying the kidney do not anastomose, each such "end" artery providing for a particular area of renal substance. On reaching the level of the bases of the renal pyramids, each interlobar artery breaks up into a tree-like bundle of twigs, some of which pursue an arched course across the bases of the pyramids, thereby producing the impression of a series of arcades at the junction of the medulla and cortex. From these vessels two series of terminal branches arise, one for the supply of the cortex, the other for that of the medulla.

FIG. 1611.



Corrosion preparation of injected right kidney, viewed from behind, showing relations of branches of renal artery to divisions of renal pelvis.

The *cortical arterioles* pursue a course generally perpendicular to the free surface, towards which they run between the cortical lobules, giving off short lateral twigs that end as the vasa afferentia in the glomeruli of the Malpighian bodies. The latter are arranged in columns in correspondence with the path of the interlobular cortical arterioles. Some of these, however, do not give off vasa afferentia, but ascend to the kidney capsule, for the supply of which they provide in conjunction with the direct branches from the renal artery.

After traversing the capillary complex, the blood is carried from the glomerulus by the vas efferens, which, smaller than the vas afferens, on its exit immediately breaks up into the *cortical capillaries* that form net-works enclosing the tubules within the labyrinth, and, continuing, surround those within the medullary ray, in the latter situation the meshes being relatively longer and more open and containing blood that has already supplied the proper uriniferous tubules.

The *medullary arterioles*, derived in part from the terminal branches of the interlobar stems at the bases of the pyramids, descend within the latter as bundles of radially disposed

straight twigs (*arteriolæ rectæ*) that at first surround the groups of collecting tubules and then break up to take part in forming the capillary net-work of the medulla. From these meshes the blood is collected by the straight venous radicles that accompany the arterioles and, with the latter, constitute the *vasæ rectæ*, owing to whose presence the darker striæ of the medulla are due. In consequence of numerous anastomoses the vascular supply of the medulla is less independent of that of the cortex, than was formerly supposed (Huber).

Veins.—The veins of the kidney are also disposed as cortical and medullary branches which empty into larger stems (*venæ arciformes*) that cross the bases of the pyramids as a series of communicating venous arcades.

The blood within the cortical capillaries escapes by three paths: (1) through numerous small veins that traverse the outer third of the cortex towards the capsule, beneath which they empty into larger stems running parallel to the free surface of the kidney. From three to five of these horizontal vessels converge towards a common point and thereby produce a star-like figure (*vena stellata*), which is the beginning of the *interlobular vein* that, in company with the corresponding arteriole, passes through the cortex to become tributary to the venous arcade at the base of the pyramid; (2) through small venous branches that empty directly into the interlobular veins at various levels; (3) through the deep cortical veins that traverse the inner third of the cortex and are tributaries of the venæ arciformes. The medulla is drained by the *venulæ rectæ*, straight vessels that begin in the medullary capillary net-work and empty into the arciform veins. The latter terminate in the larger interlobar veins that accompany the arteries along the sides of the pyramids and emerge into the sinus around the papillæ. The further course of the relatively large and valveless venous trunks corresponds with that of the arteries; the veins draining each half of the kidney unite into a single stem, the two thus derived joining to form the renal vein. The latter usually lies anterior to the renal artery in its path to the vena cava, the left vein being longer than the right in consequence of the position of the cava on the right of the spine.

FIG. 1612.

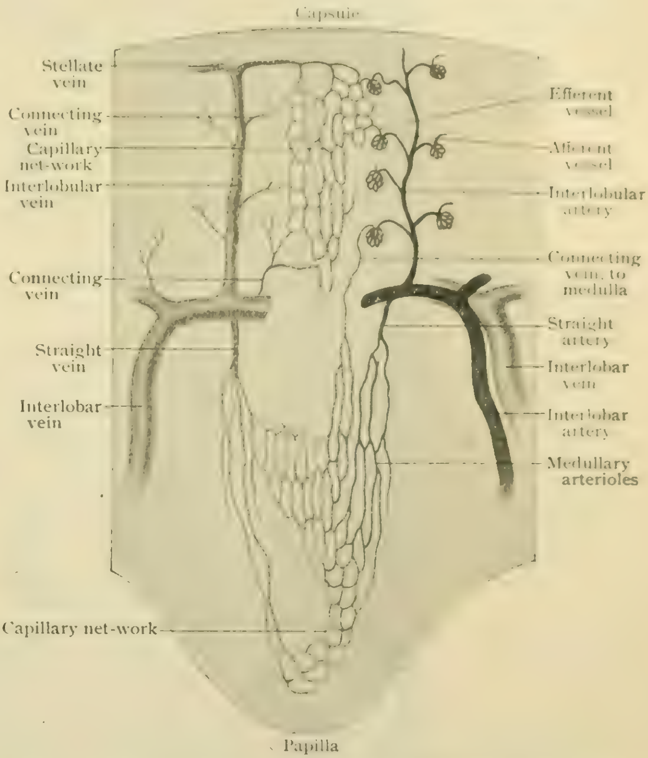


Diagram showing arrangement of blood-vessels of kidney. (*After Disse.*)

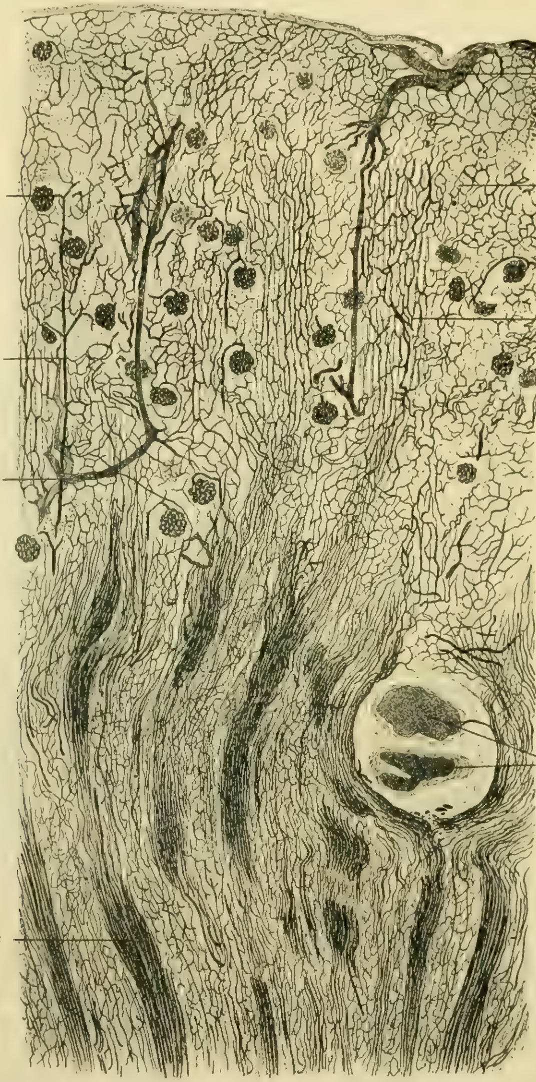
The **lymphatics** of the kidney occur as a superficial and a deeper net-work. According to the investigations of Stahr[1] and of Cunéo,[2] the *superficial lymphatics* comprise a delicate subcapsular mesh-work from which two systems of collecting trunks arise; the one passes into the kidney to join the deeper lymphatics within the renal substance, the other pierces the capsule to unite with the perirenal lymphatics within the capsula adiposa. The *deep lymphatics* arise within the cortex from delicate interlobular net-works, the general path of the more definite stems being that of the blood-vessels. On leaving the hilum, the larger collecting trunks—from four to

[1] Archiv f. Anat. u. Entwick., 1900.
[2] Bull. d. Soc. Anat., Fév. 1902.

seven in number—follow the renal artery and vein, especially the latter, which they surround. The lymphatics of the kidney end chiefly in the nodes lying at the sides or in front of the aorta ; small lymph-nodes frequently occur in the vicinity of the hilum.

The **nerves** of the kidney are derived from the renal plexus formed by contributions from the solar and aortic plexuses and the least splanchnic nerve. The

FIG. 1613.



Longitudinal section of injected kidney of dog, showing general arrangement of blood-vessels of cortex and adjacent medulla. × 40.

plexus accompanies the renal artery, which it surrounds with its mesh-work, into the sinus ; within the latter is formed a well-marked perivascular net-work from which a number of twigs are given off to supply the walls of the pelvis and ureter, while the majority accompany the vessels into the kidney. The investigations of Retzius, Kölliker, Disse, Berkley, and especially of Smirnow,[1] have shown that all the renal blood-vessels are generously provided with fibres for the supply of the muscular

[1] Anatom. Anzeiger, Bd. xix., 1901

tissue of their walls. In continuation the nerve-fibres pass between the uriniferous tubules and form plexuses surrounding the membrana propria. Smirnow traced the ultimate fibrillæ within the tubules, their free endings lying between the epithelial cells. The vessels and tubules of the medulla are provided with similar but less closely disposed nervous filaments which are destined chiefly for the muscular tissue. According to the last-named investigator, the nerves of the kidney include some sensory and both medullated and non-medullated fibres. The fibrous capsule also possesses a rich nervous supply.

Variations.—More or less conspicuous furrows are frequently seen on the surface of the adult kidney; these represent a persistence of the lobulation normally present in the fœtus and the young child.

In addition to variations in size, a marked deficiency on one side being usually compensated by a large organ on the other, the kidneys often present different degrees of union depending upon abnormal approximation or fusion of the primary renal anlages. The connection may consist of a band, chiefly of fibrous tissue, that unites otherwise normal organs; or it may be formed by an isthmus of renal tissue that extends between the approximated lower poles; or the two organs may form one continuous U-shaped mass across the spine, then constituting a "horseshoe" kidney. Extreme displacement and fusion may produce a single irregular organ whose primary double anlage is indicated by the presence of two renal ducts that descend on different sides of the pelvis to terminate normally in the bladder. Absence of one kidney occasionally occurs, the organ present usually being correspondingly enlarged. Complete absence of both kidneys has been observed as a rare congenital malformation.

PRACTICAL CONSIDERATIONS: THE KIDNEYS.

Congenital abnormalities of the kidneys may affect (*a*) their shape, size, and number; (*b*) their position; and kidneys that are abnormal in one of these respects are apt to be so in others. The matter is of practical importance in relation to the diagnosis of intra-abdominal swellings and to the many operations now undertaken for the relief of various renal conditions.

(*a*) *Anomalies as to Shape, Size, or Number.*—One kidney may be congenitally absent or greatly atrophied; may be constricted so as to assume an hour-glass shape; or lobulated, as in the fœtal condition; or the two kidneys may be fused so that (1) their inferior portions are united by a band of tissue—glandular or fibrous—that crosses the vertebral column, usually in the lumbar region ("horseshoe kidney"); or (2) they may form an irregularly bilobed mass, one side of which is much larger than the other, or become one single "disk-like" kidney lying in the mid-line on the lumbar spine, on the sacral promontory, or in the hollow of the sacrum (Rokitansky, Morris).

Of these conditions the rarest is the true congenital absence, or extreme atrophy of a kidney (1 in 2650); horseshoe kidneys are more than twice as common (1 in 1000); while one-sided renal atrophy associated with post-natal disease is relatively frequent (1 in 138) (Morris).

Both kidneys have been absent in many still-born children and acephalous monsters. In a very few cases a supernumerary kidney has been found.

Anomalies affecting the blood-supply to the kidney occur in nearly 50 per cent. of cases. The renal arteries are usually increased in number, or divide at once—before reaching the hilum—into several branches, fœtal conditions in the human species that are permanent in many birds and reptiles. Accessory or supernumerary veins are much more rarely found.

(*b*) *Anomalies of Position.*—Congenital displacement—apart from the horseshoe kidney—usually affects one kidney, which is apt to be found in the vicinity of the sacral promontory or the sacro-iliac joint, but may be either higher or lower, and may, by its malposition, give rise to serious or even fatal error in diagnosis or treatment.

It would seem proper to include here those rare temporary displacements that are due to the congenital presence of a mesonephron, which—as the usual support given by the peritoneum is lacking, and as the contained blood-vessels are in such cases of abnormal length—permits mobility of the kidney beyond the physiological limits (floating kidney).

Movable Kidney.—The extent of the normal kidney movement—of ascent during expiration or while lying supine, and of descent during inspiration or while standing erect—does not, on an average, much exceed an inch in the vertical direction. There may also be a slight lateral movement. When this limit is distinctly and greatly overpassed the condition known as "movable kidney" results. The normal kidney is usually not palpable below the costal arch. Occasionally the lower end of the right kidney may be felt there just external to the rectus muscle. In emaciation the lower ends of both kidneys may be palpable.

Three degrees of abnormal mobility have been arbitrarily but usefully agreed upon for purposes of description: (1) The lower half may be felt by bimanual palpation—the fingers of one hand being pressed into the ilio-costal space posteriorly, and of the other, into the subcostal region anteriorly—during deep inspiration. (2) The greater part of the kidney or the whole organ may be felt during deep inspiration, but ascends under cover of the ribs and liver during expiration. (3) The whole kidney descends and can be retained between or below the examiner's fingers during the respiratory movements (Morris).

The most important factors in holding the kidney in its normal position in the renal fossa (page 1874) are: (*a*) the perirenal fascia, which through its attachment to the transversalis fascia and to the perinephric fat, in conjunction with (*b*) the peritoneum, where that covering exists, prevents any undue mobility; (*c*) the renal vessels, which must correspond in length to the radius of the circle of movement of the kidney and, to an extent, resist elongation; (*d*) intra-abdominal pressure, which, through the upward thrust of the more mobile viscera, adds to the support that (*e*) they and their attachments give to the viscera in the upper zone of the abdomen; (*f*) the shape of the renal fossæ, which, like the kidneys themselves, are somewhat narrower at their lower extremities.

Undue mobility of the kidney is thus favored by (*a*) congenital absence of the peritoneal support (floating kidney,—*vide supra*); (*b*) diminution of the tension of the peritoneum and perirenal fascia from absorption of perinephric fat; (*c*) repeated jars and jolts, as from jumping or falling, or from coughing or straining, that tend to elongate the renal vessels as well as to stretch the peritoneum and its attachments and thus increase both the retroperitoneal space in which the kidney moves and the radius of the arc of its movement; (*d*) pregnancy, the removal of intra-abdominal tumors or of accumulations of fluid, or other conditions that produce laxity and weakness of the abdominal walls; (*e*) ptosis of other viscera, acting either by their push from above (liver, spleen) or their drag from below (colon); or (*f*) general muscular weakness, acting not only by reason of the associated lack of tonicity of the abdominal wall, but also through the modification in shape of the renal fossæ, the depth of which depends, *cæteris paribus*, on the development of the loin muscles, and especially of the psoas and quadratus lumborum.

A careful study of the body-form in its relation to movable kidney seemed to show (Harris) that a relative diminution in the capacity of the middle zone or area of the body-cavity (containing the liver, stomach, spleen, pancreas, and larger portion of each kidney), either original or acquired (as from tight lacing), acts by forcing the liver and spleen downward upon the kidneys, and at the same time depriving them of the support afforded by the narrowest or most constricted portion of the parietes of this zone, which narrow portion is then above the centre of the kidney instead of below it, as it should be normally.

Consideration of the above-mentioned anatomical factors makes clear the greater frequency (80 per cent.) of movable kidney in women than in men. It should be added that in women the renal fossæ are normally shallower and less narrowed at the lower ends than in men, the depth and the narrowing depending, as has been said, upon muscular development. It will be understood, too, why among the women who suffer from this condition is found a so considerable proportion who are thin and round-shouldered, with long, curved spines and flattening and adduction of the lower ribs, or who have had several children, or one difficult labor, or an exhausting illness attended by emaciation, or have been addicted to tight lacing. In both sexes the history of a violent fall or of a chronic cough is not infrequent.

Movable kidney is thirteen times more frequent on the right side than on the

left, because of the following conditions, which are of varying relative importance in different cases: (*a*) the left perirenal fascia is strengthened by some fibrous bands, remnants of the fusion of the descending mesocolon with the primitive parietal peritoneum (Moullin), the left kidney being thus more firmly bound to the descending colon than is the right to the ascending colon; (*b*) the greater size, weight, and density of the liver as compared with the spleen, and its more intimate association with respiratory movements, making the impact of the former on the upper surface of the right kidney both more frequent and more potent than the similar contact of the spleen with the left kidney; (*c*) the greater length of the right renal artery, which has to cross the mid-line to reach the kidney; although the right vein is similarly shorter than the left vein, it offers less resistance to elongation than does the left renal artery; (*d*) the right kidney is usually lower than the left kidney (page 1871), and therefore more easily loses the support of the parietes at the region where that support is most effective (*vide supra*); (*e*) the connection of the left suprarenal capsular vein with the left renal vein gives some fixation to the left kidney, as the capsule remains in position and does not follow the kidney in its abnormal movements (Morris, Cruveilhier); (*f*) the right renal fossa is more cylindrical—*i.e.*, less narrowed at its lower end—than the left, especially in women, owing to a slight torsion of the lumbar spine (Moullin), or perhaps to the greater width and development of the right side of the pelvis.

From an anatomical stand-point, the symptoms caused by excessive mobility are:

1. Those due to traction upon and irritation of the nerves; as, for example, *pain*, felt in the loins and often referred to the lower abdomen or genitalia, owing to the association of the renal plexus with the spermatic or ovarian plexus; the same association gives to the pain produced by pressure upon a movable kidney the sickening quality peculiar to testicular nausea (page 1951); *nausea and vomiting*, due to a similar connection with the solar plexus and pneumogastrics; *neurasthenia*, which may be either a result of movable kidney—through nerve irritation—or a cause, when it has produced emaciation and muscular weakness.

2. Those due to traction upon the gastro-intestinal tract, especially upon the duodenum and bile-ducts, as *digestive disturbance*, *flatulence*, *constipation*, and even *jaundice*. As the second portion of the duodenum is dragged upon through its areolar-tissue connection with the right kidney, its lack of mesentery prevents it from moving downward, it is stretched so that its lumen is diminished, and interference with the digestive current and secondary dilatation of the stomach follow (Bartels); at the same time the bile-ducts are elongated and narrowed and the passage of bile through them is interfered with (page 1731). On the left side similar disturbance of digestion may follow the pull of the kidney on the stomach and colon.

3. Those due to traction upon the vessels, resulting—as the compressible vein is more readily affected—in *congestion* of the kidney, sometimes so marked as to give rise to a temporary hæmaturia.

4. Those due to traction upon or angulation or twisting of the ureter, causing an acute *hydronephrosis*, at first intermittent. Tuffier has shown that the bending or kinking of the ureter when a kidney is displaced occurs in more than 50 per cent. of cases at a point a few centimetres below the pelvis, where it is held against the abdominal wall by strong connective tissue and cannot follow the moving kidney (Landau). In some cases, as a result of ureteral stenosis at the point of obstruction, secondary changes occur in the kidney which consist essentially in (*a*) an atrophy of the renal structure most directly exposed to pressure from the retained urine (Virchow); and (*b*) interstitial degeneration resulting from interference with nutrition, due to the facts that distention of the pelvis of the kidney takes the direction of least resistance, which is forward, and that the pelvis is placed behind the vessels where they enter the hilum, so that as it distends it stretches, flattens, and obstructs them (Griffiths).

As Morris has pointed out, the increased resonance and diminished resistance in the loin, described as indicating the absence of the kidney from its normal position, are of little value because (*a*) the ilio-costal space in some positions of the trunk and thigh is somewhat hollow; (*b*) the thickness of the loin muscles and of the fat makes the percussion-note dull even when the kidney is displaced; and (*c*) in its normal

position the kidney is so overlapped by the lower thoracic wall that the resonance and resistance of the loin have at best but little relation to it (page 1873).

Of course, obstruction of the ureter from other causes—as valvular folds at the ureteral orifice, thought to follow a congenital exceptionally oblique insertion of the ureter into the pelvis (Virchow), or brought about by distention of the pelvis (Simon), or aggravated by swelling of the pelvic mucosa (Küster, Cabot)—or obstructive disease of any part of the lower urinary tract may also result in a hydronephrosis which, if infection occurs,—as it often does,—becomes a *pyonephrosis*. Either a purulent collection thus formed or an abscess originating in the renal structure (pyogenic or tuberculous infection) may find its way into the fatty and connective tissue of the loin,—perinephric tissue,—or suppuration may reach that region from other sources or may occur there primarily.

Perinephric abscess is characterized by certain symptoms which should be studied in connection with the anatomy of the region, as (*a*) pain, radiating to the lower abdomen, genitalia, or thigh,—*i.e.*, in the distribution of the ilio-hypogastric, ilio-inguinal, anterior crural, obturator, and other branches of the lumbar plexus; (*b*) flexion and adduction of the thigh, from irritation of the motor filaments of the same nerves, especially if the abscess is about the lower pole of the kidney, and therefore in intimate relation with the third and fourth lumbar nerves, from which the supply of the flexors and adductors is chiefly derived; (*c*) bending of the body towards the affected side, towards which the concavity of a lateral lumbar curve in the spine is directed,—a symptom which, like *b*, may be due either to muscular spasm or to an instinctive effort to increase the loin space; (*d*) intestinal disturbance from the proximity of the abscess to the colon, into which it may open. Such abscess may also penetrate the lumbar aponeurosis and the quadratus lumborum muscle and appear in the loin at the outer border of the erector spinæ between the latissimus dorsi and external oblique (the lower part of which interval is Petit's triangle, *q.v.*), or may descend by gravity into the pelvis, or may—very exceptionally—open into the peritoneal cavity.

Abscess of the kidney which penetrates the renal capsule to reach the perirenal region usually does so at a non-peritoneal area of the kidney surface, but does not necessarily reach the loin. As reference to the relations of the kidney (page 1873) will show, the pus may be evacuated directly into the colon or duodenum, or more frequently—because the apposed areas are covered with peritoneum which favors limiting adhesions—into the stomach or liver, or through the diaphragm into the base of the chest.

Renal calculus produces symptoms which are analogous to those described above as associated with suppurative disease in or about the kidney, and which—apart from hæmaturia and pyuria and the physical evidence of the presence of a stone, such as is afforded by the X-rays—depend for their interpretation upon a knowledge of the renal reflexes,—*i.e.*, of the association of the small and lesser splanchnics and the tenth to twelfth dorsal and first lumbar spinal segments with the sensory and motor nerves derived from the same segments. These symptoms are, in part, pain radiating to the genitalia, vesical irritability, nausea and vomiting, rectal tenesmus, and retraction of the testicle. The last-named symptom is more marked in children and young persons, in whom the gland is often drawn up to the external ring or even into the inguinal canal. After puberty, as the testis increases in weight and the cremaster grows feebler with age, the retraction becomes less obvious (Lucas).

It has been suggested that occasionally the sudden exacerbation of pain occurring at night when the patient is at rest may be due to the passage of flatus along the colon that presses against the kidney (Jacobson).

The aching pain beginning at the lower edge of the last rib, in the angle between it and the spine, and extending along the edge of the rectus muscle below the level of the umbilicus, is probably reflected along the last dorsal nerve, as it is almost certainly relieved by operations in which that nerve is divided, but the stone is not found (Lucas).

Disease of the kidney, when non-suppurative, has but little obvious anatomical bearing. It may be noted, however, that the time-honored practice of applying counter-irritants and heat to the loin in renal *congestions* has a scientific basis in the

free anastomosis between the lower intercostal and upper lumbar arteries, supplying the parietes of the loin, and some terminal branches of the renal artery. This—a part of the "subperitoneal arterial plexus" (Turner)—is accompanied, of course, by a similar venous anastomosis. Thus the application of cups or hot fomentations or counter-irritants to the loin may act, at least temporarily, by enlarging superficial vessels and withdrawing blood from a congested or inflamed kidney.

In somewhat the same line of thought, as to congestion, attention may be called to the facts that the capsule and pelvis of the kidney are the sensitive portions; that renal pain, not dependent on infection, or on the irritation of a calculus, or on displacement, usually means increased tension; that great relief of both pain and congestion is therefore often experienced after nephrotomies that are merely exploratory, although, if the tension is due to accumulation of fluid within the renal pelvis, grave renal congestion may follow its evacuation and the accompanying sudden relief from habitual pressure just as it follows some cases of catheterization of habitually distended bladders (Belfield); and that occasional cures of various forms of acute or subacute nephritis, or of "albuminuria associated with kidney tension" (Harrison), have been obtained merely by splitting the kidney capsule with or without puncture of the kidney itself. The more recent attempt (Israel) to apply the method to chronic nephritis with severe or dangerous symptoms (especially colic and hæmaturia), and the still more recent introduction (Edebohls) of bilateral "decortication"—decapsulation—in chronic nephritis without such symptoms, have not at this time demonstrated their value. They are of much interest, however, in relation to the important subject of tension of the kidney and of the effects of modification of its vascular supply. The beneficial results of relief of tension in swellings of the testicle (acute orchitis) or of the eye (acute glaucoma) are pointed out as illustrations of the manner in which splitting the capsule benefits some forms of nephritis (Harrison, Israel). Decortication is supposed to act by removing a barrier—the fibrous capsule—to the establishment of collateral circulation, promoting a free supply of blood to the kidney previously impoverished by reason of the inadequacy of its vessels, and favoring the absorption of excessive interstitial connective tissue, the regeneration of renal epithelium, and the removal of injurious pressure upon the uriniferous tubules (Edebohls). The problems presented have so distinct an anatomical bearing that their mention here does not seem inappropriate.

The rich blood-supply of the kidney,—an amount of blood equal in weight to that of the organ itself flowing through it each minute during full functional activity (Tilden Brown),—while it favors congestive conditions, makes total embolic necrosis—such as occurs in other glands confined within dense capsules, as in the submaxillary salivary gland as a secondary result in angina Ludwigii (page 553) and in the testicle in some cases of torsion with complete venous and partial arterial obstruction (Gerster)—very rare, only one case (Friedlander) having been reported.

Subparietal injuries to the kidney are common, constituting 39 per cent. of visceral lesions resulting from contusions of the abdomen or loin. Rupture of the kidney by abdominal or lumbar contusion has been experimentally shown (Küster) to depend upon the effect of a force (hydraulic) acting through the full vessels and the pelvis and causing the kidney to burst, usually along the lines radiating from the hilum in the direction of the tubules,—*i.e.*, transverse to the long axis of the kidney, towards the point of maximum impact of the lower ribs, the opposing resistance being supplied by the spine (Morris). There is reason to believe that the direction of ruptures—radiating from the hilum to the periphery—is influenced by the lines of least resistance indicating the original absence of vascular loops and of their accompanying connective tissue between the adjoining lobules of which the fœtal kidney is composed.

As the ribs in immediate relation to the kidney are the eleventh and twelfth, which are rarely fractured, laceration by direct impact of broken ribs is relatively uncommon, although it does occur.

Ruptures may much more rarely be produced by muscular action alone, but in such cases the violent muscular effort that usually adducts the ribs and forces them against the kidney and towards the spine is almost always associated with forward or lateral bending of the vertebral column. Forcible anterior flexion of the spine, as

from a weight falling on the shoulders, may cause compression of the kidney between the lower ribs and the ilium, and is, therefore, not infrequently followed by hæmaturia, indicating some degree of rupture of kidney-substance.

The rupture may be (*a*) *incomplete*,—*i.e.*, may involve the parenchyma alone, the symptoms in these relatively rare cases being those of excessive renal tension (*vide supra*), the constitutional signs of hemorrhage and of toxæmia (usually due to urinary extravasation or to perinephric cellulitis) being moderate or lacking; (*b*) *complete internally*,—into the pelvis of the kidney,—a more common condition, in which hæmaturia, acute hydronephrosis, from blocking of the ureter with blood-clot, and vesical irritability are prominent symptoms, and the constitutional signs of hemorrhage and toxæmia are more marked; (*c*) *complete externally*,—extending through the fibrous capsule,—in which, in addition to the immediate indications of hemorrhage and the later symptoms of sepsis, the usually free urino-sanguineous effusion into the loin produces marked lumbar swelling and tenderness; or (*d*) *complete*,—running from the pelvis to and through the capsule,—in which, with a commingling of the above symptoms, there is often profound shock which may terminate fatally.

Rupture of the kidney extending through its outer surface may be (*e*) *transperitoneal*, in which case hemorrhage is apt to be very free, as there is no surrounding pressure to resist and limit the extravasation, and fatal peritonitis will almost surely follow unless the escaped urine is normal, acid, and sterile, and unless both it and the blood-clots are speedily evacuated.

When, in addition to the laceration of the kidney, a single intraperitoneal organ is also injured, it is always on the same side as the injured kidney (Watson). The liver, for example, or the ascending colon, may be involved in a case of subparietal rupture of the right kidney, but never the spleen or the descending colon. This will readily be understood from a consideration of the frequency with which the cause of rupture is a forcible forward bending of the vertebral column, the kidney being caught in the angle of the bend, any lateral deviation of which may determine the side on which the injury occurs and the involvement of liver or spleen respectively.

Transperitoneal rupture of the kidney is relatively far more common in children than in adults. Until the age of eight or ten years is reached the kidney lacks its covering of perinephric fat, and its anterior surface lies in contact with, and is closely connected to, the peritoneum. A rupture involving that surface is therefore practically certain to open the peritoneal cavity and is likely to be followed by excessive hemorrhage and septic infection. In children under ten years of age 85 per cent. of subparietal ruptures of the kidney have proved fatal (Maas).

Wounds of the kidney must, of course, involve the capsule and external surface, so that hemorrhage into the perinephric tissues is an almost constant symptom. If the wound has reached the calyces or the pelvis, urine will be commingled with the blood. Vesical hæmaturia may be prevented by the presence of a clot in the ureter, or by the actual severance of that tube. If large vessels have been opened, the blood, in addition to reaching the bladder or the perinephric space or the peritoneal cavity, may pass upward to the diaphragm, downward to the iliac fossa, or along the spermatic vessels to the external abdominal ring, or outside of the ureter to the perivesical space, or forward between the two layers of the mesocolon. In a reported case of gunshot wound in which the missile reached the kidney from above downward, injuring pleura and diaphragm *en route*, the concomitant injury to the lower intercostal nerves caused rigidity and tenderness of the anterior abdominal wall and gave rise to the unfounded suspicion that the wound was transperitoneal.

Anuria due to reflex effect upon the normal kidney may follow a rupture or wound or even calculous irritation of the other kidney, although, as a rule, calculous anuria indicates a bilateral lesion. Both kidneys are, of course, supplied from the same segments—the tenth, eleventh, and twelfth dorsal and first lumbar—of the spinal cord. Excessive tension from compensatory hyperæmia has been thought to explain this form of anuria, and the theory is supported by the facts that the condition sometimes follows a nephrectomy, the remaining kidney being normal, and that, whatever its cause, it is often relieved by nephrotomy of the hitherto sound kidney. The susceptibility of the kidney to reflex stimulation or inhibition must be admitted,

however, as cases of both polyuria and threatened suppression have followed the gentle and partial insertion of the ureteral catheter (Tilden Brown).

Tumors of the kidney have, as a class, the following distinctive anatomical characters, which have been well summarized by Morris:

(*a*) The large intestine is in front of the tumor. Normally the right kidney, unless enlarged, lies a little way from the lateral wall of the abdomen, behind and to the inner side of the ascending colon; not in close contact with the abdominal wall and outside the ascending colon, as the liver does. When the kidney is enlarged, the ascending colon is usually placed in front of and towards the inner side of the tumor. On the left side the descending colon is in front of, and inclines towards the outer side of, the kidney below; in some cases coils of small intestine may overlie either right or left tumor if the enlargement is not sufficient to bring the kidney into direct contact with the front abdominal wall. When the colon is empty or non-resonant, it can be felt as a roll on the front surface of the tumor. Bowel is not thus found in front of splenic tumors and very rarely in front of a tumor of the liver.

(*b*) There is no line of resonance between the kidney dulness and the vertebral spine, and no space between the kidney and the spinal groove into which the fingers can be dipped with but little relative resistance, as there is between the spleen and the spine.

(*c*) While a renal tumor fills up the "hollow of the back" somewhat, it does not often protrude or project backward. Marked posterior projection usually indicates perinephric swelling, as from an abscess or a urino-sanguineous effusion.

(*d*) A kidney tumor can sometimes be recognized by its proneness to maintain an outline resembling that of the normal kidney.

(*e*) A kidney swelling, if inflammatory in origin, descends less in inspiration than does a splenic, hepatic, or adrenal swelling; this symptom in a case of new growth is not very valuable, as the renal tumor may have a considerable degree of movement.

(*f*) As a rule, kidney tumors do not reach the mid-line, do not invade the bony pelvis, and are separated from the hepatic dulness by a line of resonance. If large enough, the tumor may reach the anterior abdominal parietes about the level of the umbilicus, but external to it.

(*g*) In large renal tumors varicocele, from compression or distortion and distention of the spermatic vein, has been noticed in a number of instances.

Operations upon the kidney for its fixation (nephrorrhaphy, nephropexy), for drainage or relief of tension (nephrotomy), for the extraction of a calculus (nephrolithotomy), or for the establishment of collateral circulation (decortication), are almost invariably done through the loin.

The *vertical* incision—on a line about an inch posterior to the middle of the crest of the ilium and running from that level to the twelfth rib—does not, as a rule, give sufficient room, divides the last dorsal and the lumbar vessels and nerves, and hence jeopardizes the subsequent integrity of the ilio-costal wall.

The *oblique* incision begins about a half inch below the twelfth rib and at the outer border of the erector spinæ. It is well to count the ribs from above downward, as when the twelfth rib is rudimentary it may not project beyond the edge of the erector spinæ and may be mistaken for the transverse process of the first lumbar vertebra. In such circumstances the incision, having by error been made close to the edge of the eleventh rib, has, in reported cases, opened the pleura.

The oblique incision is extended forward for three or four inches parallel with the twelfth rib,—*i.e.*, with the vessels and nerves of the region. The skin and superficial fascia, the latissimus dorsi, and the external and internal oblique muscles having been divided and the lumbar aponeurosis and the transversalis fascia severed, a layer of fat will then appear or will bulge into the incision (perirenal or transversalis fat). As this is cut through or separated with fingers or forceps, a layer of connective tissue may be recognized—the posterior layer of the perirenal fascia—and then a second layer of fat (perinephric fat, capsula adiposa), which is sometimes finer in texture and more distinctly yellowish (Morris), and which, if it is incised or torn through and drawn into the wound, will present a funnel-shaped opening leading down directly to the kidney (Gerota), which can then often be isolated by blunt

dissection with the finger, and either stitched in place, decapsulated, or opened, in accordance with the indications.

It may be noted that bleeding from the separation of the capsule is comparatively trifling; and that if the kidney itself is to be incised, the fact that its blood-supply is naturally divisible into two independent segments—anterior and posterior—which are completely separated by the renal pelvis, and the vessels of which are given off from the main trunk of the renal artery (Hyrtl), indicates, as the line of safety, the convex posterior or outer border. When the pelvis of the kidney is distended with fluid, a white line on that border (Brödel's line) is said to indicate the relatively avascular area. The anterior vascular division is said to carry three-fourths of the arterial blood-supply and the posterior division the remaining fourth (Brödel), so that in the majority of cases the posterior surface of the kidney would furnish the lesser quantity of blood.

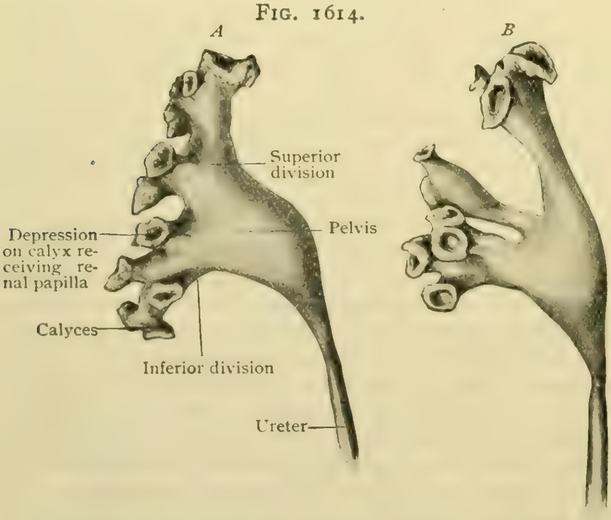
For removal of the kidney (nephrectomy) the oblique incision may be prolonged forward, the peritoneum being detached and pushed in that direction ; or a vertical incision running downward from it may be added ; or, if the nephrectomy is to be done for the removal of an exceptionally large tumor, the anterior or transperitoneal route may be adopted and the incision made in either the linea semilunaris or the linea alba, the outer layer of the mesocolon being opened to gain access to the retroperitoneal space. The nerves and vessels, as they enter the hilum of the kidney, the vein lying in front, constitute the "pedicle." The ureter lies more posteriorly and on a slightly lower plane. The irregularities in the division, distribution, and points of entrance of the renal artery should be remembered, as should also—on the right side—the proximity of the vena cava during the separation of close adhesions.

In all the lumbar operations upon the kidney the colon may present in the wound after the transversalis fascia has been opened, and should be looked for and displaced antero-externally to avoid danger of wounding it.

THE RENAL DUCTS.

The duct of the kidney—the canal which receives the urine as it escapes from the kidney and conveys it to the bladder—consists of a short dilated and subdivided upper segment, the *renal pelvis*, and a long, narrow, tubular lower segment, the *ureter*. Since not only these but also the papillary ducts of the kidney are developed from a common outgrowth from the Wolffian duct, the renal duct stands in most intimate relations with the renal substance.

FIG. 1614.



Casts obtained by corrosion, showing two forms of renal pelvis: *A*, usual type; *B*, variation.

The **pelvis of the kidney** (**pelvis renalis**), although beginning and lying chiefly within the sinus, extends beyond the latter, passing downward to become continuous with the ureter. Its widest part, just within the hilum, presents an unbroken convex posteromesial surface, its opposite side, directed towards the renal substance, being interrupted by the subdivisions of the pelvis. These include the divisions of the pelvis into an *upper* and a *lower segment* (calyces majores), extending towards the respective poles of the kidney. Each of these segments receives a group of from four to six smaller conical passages, the *calyces* or *infun-*

dibula (**calyces minores**), that proceed from the renal substance, where they surround the papillæ.

The latter are embraced by the expanded bases of the conical calyces, the walls of which are intimately blended with the kidney-substance around the sides of the free part of the papillæ, a narrow cleft separating the latter from the enclosing calyx. The epithelium of the papillary ducts is directly continuous with that lining the calyx, while the subepithelial tissue of the latter blends with the intertubular renal stroma. On laying open the calyx, the papilla is seen as a conical elevation projecting into the funnel-shaped envelope (Fig. 1598); although usually enclosing a single papilla, the calyx may receive two or even more such projections.

The two general groups of calyces—an upper and a lower—open into the two large primary subdivisions (*superior* and *inferior pelvis*) that join to produce the main compartment of the pelvis. The lower end of the latter emerges through the hilum and arches downward to pass—about midway between the hilum and the inferior pole of the kidney—insensibly into the ureter; exceptionally this junction is marked by a constriction in the lumen of the canal. Although surrounded in its upper part and smaller divisions by the branches of the renal blood-vessels, the general position of the pelvis within the sinus and as it emerges through the hilum is behind the blood-vessels, the intervals between the renal duct and the other occupants of the sinus being filled with adipose tissue. On the right side the lower part of the pelvis is covered in front by the second part of the duodenum; on the left by the pancreas.

The Ureter.—This part of the renal duct is a flattened tube which connects the renal pelvis with the bladder. It lies beneath the parietal peritoneum, embedded within the subserous tissue and surrounded by fat, and descends along the posterior abdominal wall to the pelvic brim; crossing the latter, it follows the lateral wall of the pelvis, curving downward, forward and finally inward along the pelvic floor, to reach the bladder. The general direction of its course is indicated by a vertical line on the surface of the abdomen drawn from the junction of the inner and middle thirds of Poupart's ligament (Tourneux). The average length of the undisturbed ureter is approximately 27 cm. (10.5 in.), the left duct being usually about one centimetre longer than the right in consequence of the higher position of the corresponding kidney. Apart from the uncertainty of determining just where the pelvis ends and the ureter begins, its length is influenced by several factors, such as the level of the kidneys and of the bladder, the descent of the renal pelvis, body height, and sex, so that considerable variation is encountered; the excessive figures sometimes given are probably based upon measurements of the ducts after removal and abnormal relaxation. The diameter of the ureter—from 4–5 mm.—is not uniform, since at certain points, corresponding to changes in the direction or relations of the canal (Solger), constrictions regularly occur, near which the tube exhibits fusiform dilatations or spindles (Schwalbe). The most constant narrowings are situated (1) from 4–9 cm. (1½–3½ in.) below the hilum, at which point—the *upper isthmus* of Schwalbe—the diameter of the canal is reduced to almost 3 mm.; (2) near the pelvic brim as the duct crosses the iliac vessels (*lower isthmus*), preceded by a fusiform enlargement (*chief spindle*); and (3) at the lower end of the ureter as the canal penetrates the wall of the bladder. Since its course and relations vary in different parts of its path, the ureter is divided for description into an abdominal and a pelvic portion.

The **abdominal portion** (**pars abdominalis**)—from 13–14 cm. (about 5–5½ in.) in length—begins a short distance below the hilum and descends upon the anterior surface of the psoas magnus muscle and its fascia towards the sacro-iliac articulation, with a slight inclination towards the mid-line (Fig. 1591). The distance between the two ureters at their upper ends is about 9 cm. (3½ in.) and at the pelvic brim about 6 cm. (2⅓ in.). Just before reaching the latter level the ureters obliquely cross the common iliac vessels, approximately the point at which the artery divides into its external and internal divisions, or, especially on the right side, they may pass over the external iliac vessels instead. About midway in their course to the pelvis both ducts are crossed in front, at a very acute angle, by the spermatic (or ovarian) vessels and behind and obliquely by the genito-crural nerve. The right ureter passes

behind the descending part of the duodenum, lies to the right of the inferior vena cava, which it approaches and even touches in its descent, and is covered by the attachment of the mesentery. Above the left ureter may be covered by the pancreas when that organ is unusually broad, and below it is crossed by the attachment of the sigmoid flexure.

The **pelvic portion** (pars pelvina)—from 12–13 cm. (5 in.) in length—lies against the lateral wall of the pelvis, close beneath the serous membrane embedded within the subperitoneal tissue, and curves downward and forward to about the level of the ischial spine, where it turns inward upon the visceral layer of the pelvic fascia to reach the dorsal wall of the bladder (Fig. 1619). In its descent it lies in front of the internal iliac artery as far as the greater sciatic notch (Merkel), crosses the obliterated hypogastric artery and the obturator nerve and vessels to their inner side, and, as it traverses the pelvic floor, is surrounded by the tributaries from the vesical plexus to the internal iliac vein and may lie upon the middle and inferior vesical arteries. The ureter is crossed on its inner side by the vas deferens, and pierces the bladder-wall immediately in front, or under cover of the anterior part, of the seminal vesicle or of the ampulla (Fraenkel[1]). The space between the ureter and the seminal vesicle, which when the bladder is empty may be considerable, is filled by areolar tissue containing veins and fat. The relations of the ureter to the bladder are peculiar, since, in addition to penetrating the latter so obliquely that the last 18 mm. (¾ in.) of the renal duct are embedded within the vesical wall, the muscular tissue of the latter is seemingly prolonged (page 1897) over the ureter outside the bladder for some 5 mm. as a distinct sheath (Waldeyer). The ureteral orifices on the inner surface of the vesical wall are slit-like and valvular in form and, in the contracted condition of the bladder, about 2.5 cm. apart, this distance being increased twofold or even more when that organ becomes distended.

FIG. 1615.

Sagittal section through sinus of child's kidney, showing lower part of pelvis and commencement of ureter. × 10.

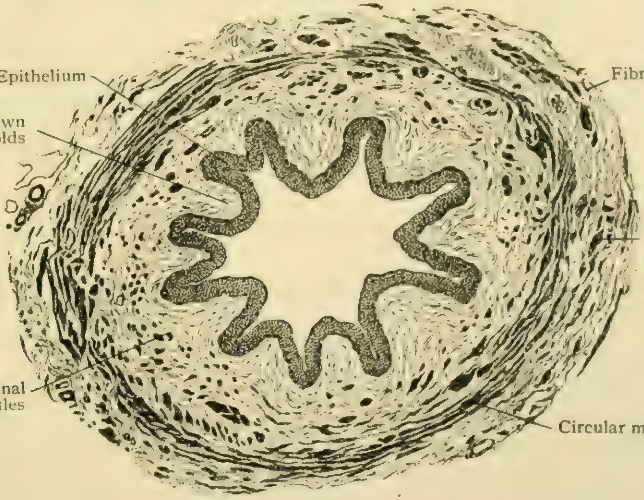
The **female ureter** (Fig. 1622) calls for special description on account of the relations of its pelvic portion to the generative organs. On gaining the lateral wall of the pelvis, the ureter descends in close proximity to the unattached border of the ovary and constitutes the postero-inferior boundary of the ovarian fossa (page 1986). On the pelvic floor the ureter enters the base of the broad ligament, within which duplicature it is crossed by the uterine artery, passes between the veins of the vesicovaginal plexus, and continues downward and forward in the vicinity of the uterine cervix to the vagina; its terminal segment lies embedded within the connective tissue between the cervix and bladder, close to the anterior vaginal wall for a distance of from 1–1.5 cm., where, bending somewhat inward, it reaches the posterior vesical wall, which it pierces obliquely in the manner above described.

Structure.—The wall of all parts of the renal duct is the same in its general construction and includes three layers, (1) the mucous membrane, (2) the muscular tunic, and (3) the outer fibrous coat; the mucosa and the muscular layer are

[1] Die Samenblasen der Menschen, Berlin, 1901.

more or less blended, a distinct submucosa being wanting. The *mucous membrane* is clothed with "transitional" epithelium consisting of several strata of cells, the superficial elements being plate-like and the deepest ones irregularly columnar. The tunica propria constitutes a subepithelial layer of fibro-elastic tissue which blends with the subjacent muscular tunic. Within the ureter the mucous membrane is usually thrown into longitudinal folds, and in consequence in transverse section the lumen of the canal appears stellate. Neither well-marked papillæ nor true glands are present, although in places the subepithelial tissue invades the epithelium and subdivides the latter into nest-like groups of cells. Occasional aggregations of lymphoid cells occur, which in the vicinity of the calyces sometimes form distinct minute lymph-nodules within the mucosa (Toldt). On the papillæ the epithelium lining the renal duct passes uninterrupted into that of the papillary canals, while the underlying tunica propria becomes continuous with the intertubular renal stroma. The *muscular tunic* consists of bundles of the involuntary variety disposed as a thin inner longitudinal and a chief external circular layer. Within the renal pelvis and its larger subdivisions both layers are well represented, but are reduced on the calyces; at the junction of the latter with the kidney the circular muscle increases and surrounds the papilla with a minute sphincter-like bundle (Henle). Except in the upper part of the renal

FIG. 1616.



Transverse section of ureter. × 25.

duct, an additional imperfect outer longitudinal layer of muscle is represented by irregularly scattered bundles. The *fibrous coat*, or tunica adventitia, composed of bundles of fibrous and elastic tissue, invests the renal duct as its outer tunic and connects it with the surrounding areolar tissue. At the kidney the outer coat of the renal duct blends with the tunica fibrosa that invests the renal substance between the calyces. Beginning several centimetres above the bladder, the adventitia of the ureter is strengthened and thickened by robust longitudinal bundles of involuntary muscle that follow the duct to its vesical orifice and, in conjunction with the fibrous tissue in which they are embedded, form the *ureteral sheath* (Waldeyer). According to Disse, this muscle belongs to the wall of the ureter and is distinct from the musculature of the bladder.

Vessels.—The *arteries* supplying the different segments of the renal duct are derived from several sources. Those distributed to the pelvis and the adjoining part of the ureter are small branches from the renal artery, the abdominal portion of the canal being additionally supplied by twigs given off from the spermatic (ovarian) artery as the latter crosses the duct and by a special vessel (a. ureterica) proceeding from the internal or common iliac artery or from the aorta (Krause). The pelvic portion receives branches from the middle hemorrhoidal or the inferior vesical arteries. The

vessels from these several sources anastomose and produce a net-work that encloses the canal and sends twigs that break up into capillaries that supply the coats composing its wall. The *veins* begin within the mucosa, beneath which they form an internal plexus that communicates with a wider-meshed outer plexus within the fibrous coat, from which tributaries pass to the internal or common iliac and the spermatic veins. The *lymphatics* within the mucous membrane and submucosa, according to Sakata,[1] are not demonstrable as distinct net-works, but as such are seen within the muscular tissue and on the surface. The lymph-trunks from the middle third of the ureter, which are the most numerous, pass to the lumbar nodes; those from the lower segment are tributary to the internal iliac nodes or communicate with the lymphatics of the bladder; while those of the upper part either empty into the aortic nodes or join the renal lymphatics.

The **nerves** of the renal duct, derived from the sympathetic system, accompany the arteries and come from the renal, spermatic, and hypogastric plexuses. Within the adventitia they form a plexus containing numerous microscopic ganglia, the largest of which are at the upper and lower ends of the duct. In addition to the fibres supplying the blood-vessels, both medullated and non-medullated fibres pass to the muscular and mucous coats.

Variations.—These consist most often in more or less complete doubling of the canal on one or both sides. While subdivision of the pelvis into an unusual number of tubular calyces is rare, its cleavage into two separate compartments, either alone or in correspondence with doubling of the ureter, is relatively common. The division may be so complete that the two resulting ducts open into the bladder by separate orifices. The termination of the ureter in the seminal vesicle—a malformation occasionally encountered—depends upon the close embryological relations (page 2039) which exist between the two structures. While congenital absence of the kidney is not necessarily associated with entire absence of the ureter, failure of the latter to develop implies incompleteness or absence of the kidney, since a part of the duct-system of the latter is derived from the primitive ureter (page 1937).

PRACTICAL CONSIDERATIONS: THE URETERS.

The ureters may be multiple from a fused kidney, or two or more ureters may spring from the pelvis of a single kidney, indicating a defect in the development of the primary fœtal ureter. The separate ureters may unite at any point between the kidney and the bladder or may remain distinct throughout.

Marked obliquity of insertion of the ureter into the pelvis (page 1896) may leave on a lower level than the ureteral origin a pouch of the pelvis—corresponding to the lowest of its original subdivisions—which, when it fills with urine, compresses the upper end of the ureter, narrows its lumen, and favors the production of hydronephrosis. This condition may also occur in either the second or third of the following variations in the upper end of the ureter thus described by Hyrtl: (*a*) there is no pelvis, but the ureter divides into two branches without dilatation at the point of division, each branch having a calibre a little larger than that of the ureter; (*b*) there is a pelvis,—that is, a funnel-shaped dilatation at the point of division; the upper portion is the smaller, and terminates in three short calyces; the lower and more voluminous portion terminates in four or five calyces; (*c*) there is only half a pelvis,—that is, the lower branch divides and is funnel-shaped, forming a narrow pelvis, which terminates in one, two, or three short calyces; while the upper is not dilated, and extends to the upper portion of the kidney as a continuation of the ureter (Fenger).

The lower end of the ureter may in the male, as a rare anomaly, open within the boundaries of the sphincter vesicæ, or into the prostatic urethra, or into the seminal vesicle, ejaculatory duct, or vas deferens.

As the opening is never anterior to the compressor urethræ, incontinence of urine does not result, but interference with its free exit causes ureteral dilatation and hydronephrosis.

In the female the ureter may open into the urethra, vagina, or vestibule. There may be incontinence of urine, or again such obstruction as to cause uretero-renal dilatation.

[1] Archiv f. Anat. u. Entwick., 1903.

These anomalies are readily understood by reference to the embryology of the ureter (page 1937).

Ureteral calculus is most often arrested (*a*) at a point from 4–6.5 cm. (1½–2½ in.) from the renal pelvis; (*b*) at the point where the ureter crosses the iliac artery; (*c*) at the junction of the pelvic and vesical portions; (*d*) at its vesical orifice. At these places normal narrowings are found in the majority of subjects. The symptoms of calculus impacted in the ureter are difficult of distinction from those of stone occupying or engaging in the pelvis of the kidney, but it may be said that if, after the usual phenomena of renal colic, vesical symptoms are marked and persistent, and especially if they are associated with slight hæmaturia and no calculus is detected in the bladder, the existence of stone in the ureter should be strongly suspected. The bladder-symptoms—irritability, frequent urination, tenesmus—will be more marked the nearer the situation of the stone to the lower end of the ureter. The relations of the nerve-supply of the ureter with that of the bladder and the genitalia and with the great intra-abdominal plexuses sufficiently explain the chief subjective symptoms of calculus.

Complete and sudden blocking of the ureter by a calculus often produces an acute hydronephrosis, the symptoms of which may overshadow those directly referrible to the region of impaction. The muscular walls of the ureter are capable of strong contraction, and, indeed, the painful "colicky" symptoms attending the passage of a stone along the ureter would better be described as "ureteral" rather than "renal."

At present the diagnosis of ureteral stone and its localization are to be made with much certainty by the X-rays.

In an effort to find tenderness which, in the presence of the above symptoms, might locate a stone, or might determine the region of *rupture* or other ureteral injury, or might confirm a diagnosis of *ureteritis* or of *tuberculous infiltration* (as a result of ascending or descending infection), it should be noted that the beginning of the ureter, the lower extremity of the kidney, and the level of origin of the spermatic or ovarian artery are all approximately defined by Tourneur's point, which is situated at the intersection of a transverse line between the tips of the twelfth ribs, with a vertical line drawn upward from the junction of the inner and middle thirds of Poupart's ligament; the course of the abdominal portion of the ureter corresponds to the same vertical line. Tourneur considers its direction vertical from the border of the kidney down to the pelvic brim, over which it passes 4½ cm. (2 in.) from the median line. The exact location of this point is the intersection of a horizontal line drawn between the anterior superior iliac spines and a vertical line passing through the pubic spine. Morris thinks that this point would usually be too low and too far inward, and that the junction of the upper and middle thirds of the line for the iliac arteries (page 819) better indicates the point of crossing of the ureter over the artery. At this point, under favorable circumstances, a dilated or tender ureter may be felt by gentle, steady pressure backward upon the abdominal wall until the resistant brim of the pelvis is reached. The vesical portion of the ureter can be palpated in man through the rectum. Guyon has called attention to the exquisite sensitiveness of this portion of the ureter upon rectal exploration in cases of stone, even when the calculus is located high up. In woman vaginal examination permits the palpation of the ureter to an extent of two or even three inches, as it runs beneath the broad ligament in close relation to the antero-lateral wall of the vagina (Cabot, Fenger).

Morris gives the following directions for palpating the lower extremity of the ureter:

(*a*) *Vaginal Palpation.*—The part of the ureter which is capable of being felt through the vaginal wall is about three inches or a little less, or, roughly speaking, about a quarter of the whole length of the duct. It is that part which extends from the vesical orifice of the ureter backward, outward, and upward to the base of the broad ligament and towards the lateral wall of the true pelvis.

It is in the superior third of the anterior and lateral wall of the vagina that the examination must be made, and it is at the part between the level of the internal orifice of the urethra and the anterior fornix, where the tissues are very lax, that the

ureter will be most readily felt. The examination should be made very gently, and the finger should be passed comparatively lightly over, not pressed firmly against, the vaginal surface. The ureter courses about midway between the cervix uteri and the wall of the pelvis, and by hard pressure the ureter is displaced before the finger in a direction towards the pelvic wall. The uterine artery or the muscular fibres of the obturator internus or levator ani (Sänger) should not be mistaken for the ureter.

(*b*) *Rectal Palpation.*—The lower extremity of the ureter, when occupied by a foreign body or in a state of disease, can be felt through the rectum in the male, but less readily than through the vagina in the female. A calculus impacted in the lower end of the ureter has been located and removed through the rectum. It is through the antero-lateral wall of the bowel and a little higher than the level of the base of the vesicula seminalis that we feel for the ureter. The pulp of the finger should be directed towards the back of the bladder and pushed as far as possible beyond the upper edge of the prostate; afterwards the finger-pulp should be turned towards the lateral wall of the pelvis, and whilst still pushed as far as possible, it should traverse the wall of the rectum forward and backward. The examination is difficult, and if the prostate is much enlarged the detection of the ureter is impossible. The normal ureter is not likely to be distinguished, even if the perineum be thin and the prostate normal.

(*c*) *Vesical palpation*—through the dilated urethra of the female—may disclose dilatation, œdema, prolapse, or infiltration, inflammatory or tuberculous, of the vesical end or orifice of the ureter, or may reveal the presence of an impacted calculus.

Wounds or subparietal injuries of the ureter, unassociated with other intra-abdominal lesions, are rarer than similar injuries of the kidney, decrease in frequency from above downward, and, on account of the bony protection afforded it, are very uncommon in the pelvic portion of the ureter.

The upper portion may be crushed against the transverse process of the first lumbar vertebra (Tuffier), or so stretched as to tear or sever it (Fenger).

Unless the escape of urine from an external wound occurs, the symptoms are merely those of ureteral irritation, usually with slight transient hæmaturia and the evidence of slow urinary extravasation superadded.

After extraperitoneal rupture or wound the swelling due to extravasated urine and subsequent cellulitis might be recognized in the loin or detected by rectal or vaginal examination in the pelvis. Longitudinal wounds gape less (and therefore heal more readily) than transverse wounds, on account of the longitudinal disposition of the thicker internal layer of muscular fibres.

Tumors of the ureters are almost unknown as primary conditions, but consideration of the relations of the ureter (page 1895) will show that it may be pressed upon by growths or involved in inflammatory processes originating in the cæcum or in the ascending or descending colon. Its pelvic portion is more exposed to pressure than is the abdominal on account of the counter-resistance of the pelvic walls, and here it may be compressed by fecal masses in the sigmoid or rectum, by iliac aneurism, or by growths of the uterus, ovary, or Fallopian tube, or may become involved in disease of the appendix when it occupies a pelvic position, or of the bladder or seminal vesicles.

The tough, resistant character of the walls of the tube, the laxity of the connective tissue in which it lies, the layer of loose fat that, in part of its course, surrounds and protects it in well-nourished individuals (Luschka), and its rich vascular supply (from the renal, spermatic or ovarian, and vesical arteries) enable it to resist or avoid injury or to undergo speedy repair. It is thus possible to separate it extensively from surrounding structures during operations with little or no risk of necrosis.

The oblique course of the ureter through the vesical wall subjects it to pressure when the bladder contracts, or when it becomes rigid from arterio-sclerotic disease. Frequency of urination alone has been thought competent—by the constantly recurring obstruction to the entrance of urine into the bladder—to produce ureteral dilatation and hydronephrosis. As its obliquity leaves it on the inner aspect covered by mucous membrane only, and as the outer aspect is covered by the muscular layer of

the bladder-wall, it can be understood that incision of the mucosa over the intra-parietal part of the ureter, for the purpose of extracting a calculus, involves little risk of pelvic cellulitis from extravasation of urine. It cannot be said that there is no risk, as in one case a peritoneal fistula and death resulted (Thornton).

Operations upon the ureter are frequent for the extraction of a calculus (uretero-lithotomy); or the extirpation (ureterectomy) of an infected ureter (tuberculous or pyogenic) either at the same time with its kidney (nephro-ureterectomy) or at a later period; or for the closure of wounds or fistulæ, or the relief of stricture, or the implantation of the distal end of the ureter—after removal of a diseased, injured, or obliterated portion—into the bladder, rectum, or elsewhere.

The anatomical factors relating to these operations cannot here be described, but it may be said generally that whenever it is possible the extraperitoneal route is selected to lessen the danger of peritonitis, and that the oblique lumbar incision employed to reach the kidney (page 1893) will, if prolonged downward and forward parallel to Poupart's ligament and to the outer edge of the rectus, give access to the whole abdominal ureter and to the upper part of its pelvic portion. Cabot has shown that the ureter is bound to the external—or under—surface of the peritoneum by fibrous bands, and that when that membrane is stripped up from the posterior abdominal wall the ureter accompanies it. He found that the relation of the ureter to that part of the peritoneum which becomes adherent to the spine is, within a slight range of variation, fairly constant, the ureter lying just outside the line of adhesion. Hence, if the surgeon has stripped up the peritoneum and has come down to that point where it refuses to separate readily from the spinal column, he will find the ureter upon the stripped-up peritoneum at a short distance outside of this point. On the left side the distance from the adherent point to the ureter is from one-half an inch to an inch, while on the right side it is somewhat greater, owing to the ureter being displaced to the outside by the interposition of the vena cava between it and the spine. It should be remembered that the peritoneum adherent to the abdominal portion of the ureter is very thin and may be torn in an attempt to separate it.

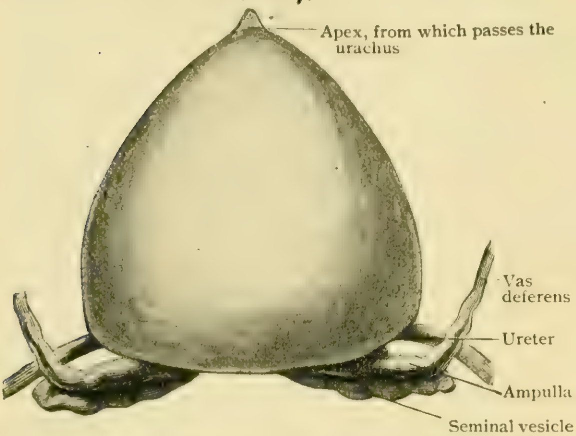
After the ureter dips down into the true pelvis it is less easily located because it has no fixed relation to a bony landmark. Cabot has suggested that osteoplastic resection of the sacrum would give access to this lower pelvic portion of the ureter. In women it can often be reached through the vagina. The ureter is, of course, accessible transperitoneally through its whole route.

THE BLADDER.

The bladder (**vesica urinaria**)—the reservoir in which the urine is received from the renal ducts and retained until discharged through the urethra—is a muscular sac, lined with mucous membrane, situated in the anterior part of the pelvic cavity immediately behind the symphysis pubis. Its form and size, and likewise to a considerable extent its relations, vary with the degree of distention, so that in describing the organ the condition of expansion must be taken into account. When containing little fluid and hardened *in situ*, the general shape of the bladder is pyriform, presenting a free, slightly convex *superior surface*, covered with peritoneum and projecting into the pelvic cavity, and a distinctly convex non-peritoneal *inferior surface*, attached by areolar tissue to the pubic symphysis and the pelvic floor upon which it rests. The urethra, surrounded by the prostate, emerges from the most dependent portion of the lower surface, behind which point the latter ascends to join the upper surface along the indistinct posterior border. The part of the bladder between the urethra and the posterior border constitutes the *fundus* or *base* (**fundus vesicae**), which in the male is in relation with the seminal ducts and vesicles and the recto-vesical pouch and is directed towards the rectum, and in the female is attached to the anterior vaginal wall. In the empty organ the superior and inferior surfaces blend along the sides in the convex *lateral borders*; anteriorly these meet at the *apex* or *summit* (**vertex vesicae**), from which a median fibrous band (**ligamentum umbilicale medium**) that represents the *urachus*—the obliterated segment of the intra-embryonic part of the allantois—extends to the umbilicus along the abdominal wall. The body (**corpus vesicae**)

includes the uncertain part of the bladder between the apex and the fundus. The term *neck* is sometimes applied to the region immediately surrounding the urethral orifice, although a distinct neck in the usual sense does not exist. The intersections of the lateral and posterior borders mark approximately the points at which the ureters enter the vesical wall. As pointed out by Dixon,[1] the attachments of the ureters correspond to the lateral angles of the trigonal figure that the empty bladder resembles when viewed from above, the apex being the anterior angle.

FIG. 1617.

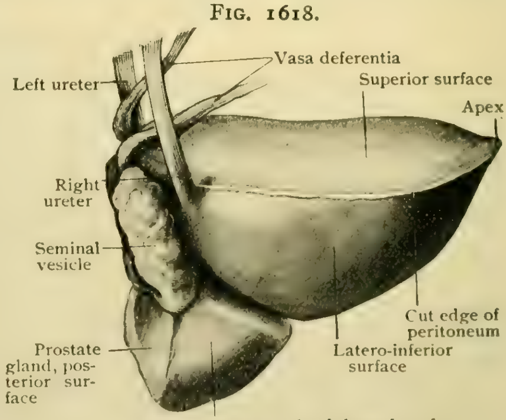


Urinary bladder, slightly distended and hardened *in situ*, from formalin subject; viewed from above.

The cavity of the *strongly contracted bladder*, as seen in sagittal sections of organs hardened *in situ*, is little more than a cleft bounded above and below by the thick vesical walls and below continuous with the urethra; in the vicinity of the ureteral orifices, however, the lumen broadens into the lateral recesses which are never entirely effaced (Luschka). The modifications of the lumen sometimes seen, more frequently in women and especially in organs not hardened *in situ*, in which the superior surface is more or less sunken and in consequence the vesical cavity is crescentic or V-shaped in mesial section, are to be regarded as the result of post-mortem change and not as representing conditions existing during life, since normal contractions of the muscular vesical sac are little calculated to produce such forms. The empty bladder measures in length from 5–6 cm. (2–2½ in.), in breadth from 4–5 cm. (1½–2 in.), and in thickness from 2–2.5 cm. (¾–1 in.) (Waldeyer).

In the *distended bladder* the demarcation between the surfaces above described is gradually effaced until, in extreme expansion, the organ assumes a general ovoid form in which the superior and inferior surfaces and the fundus are uninterruptedly continuous and all indication of the borders is completely obliterated. Such extreme changes, however, accompany only excessive and unusual distention, the alterations taking place under normal conditions, with a probable maximum capacity of from 250–300 cc. (7½–9 fl. oz.), being much less radical. When the bladder begins to fill, the region first to be affected is the posterior and lower lateral portions of the organ, expansion occurring more rapidly in the transverse than in the longitudinal axis (Delbet), which for a time retains a generally horizontal direction. With increasing distention the bladder invades the paravesical fossæ at its sides, behind is pressed against the seminal vesicles, which in the empty condition of the bladder extend laterally as transverse wings and touch the vesical wall only with their inner ends, and encroaches upon the recto-vesical pouch and the rectum. The condition of the latter also influences the direction of the vesical expansion, since the filled rectum decreases the available space behind and forces the bladder upward and forward. Not until the distention has progressed to a considerable degree does the antero-inferior segment lengthen and undergo upward displacement and the apex rise much above the pubic symphysis; and only after the distention greatly exceeds physiological limits and becomes very excessive does the bladder altogether lose its pyriform contour and become symmetrically ovoid. The highest point of the greatly enlarged organ no longer corresponds with the attachment of

FIG. 1618.

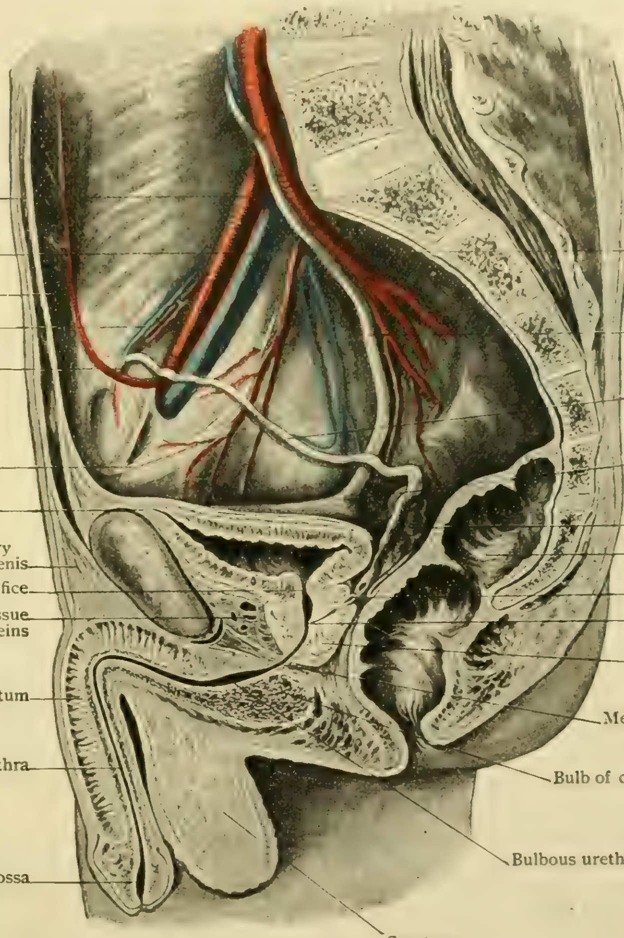


Preceding preparation viewed from side, showing relations of bladder, associated ducts, and prostate.

[1] Anatom. Anzeiger, Bd. xv., 1899.

the urachus, but lies farther above and behind, since the antero-inferior wall always remains shorter than the postero-superior. The condition of the rectum and the pressure exerted by the abdominal viscera influence in no slight degree the form and position of the distended bladder, since, when these factors are both unfavorable to unhampered expansion, the inferior surface and fundus are depressed to a greater degree than when the bowel is empty and the superior surface is little impressed by the overlying organs, the entire bladder assuming a more vertical position and the ovoid form being modified (Merkel). Under pathological conditions the bladder may suffer such enormous expansion that it reaches as high as or even above the umbilicus and occupies a large part of the abdominal cavity. Owing to its intimate attachment, the part of the inferior surface united to the prostate and the pelvic floor undergoes least change both as to form and relations.

FIG. 1619.



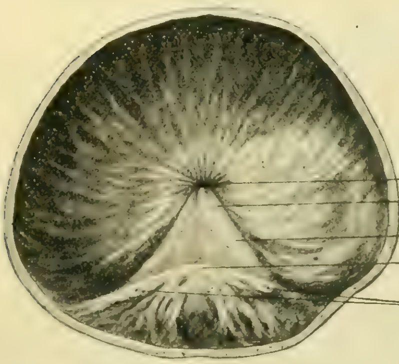
Dissection of sagittally cut pelvis, showing relations of organs after fixation by formalin injection.

The **capacity** of the bladder during life so obviously depends upon individual peculiarities and habit that it is impossible to more than indicate approximately the quantity of fluid that ordinarily induces a desire for the evacuation of the vesical contents. This quantity—the *physiological capacity* of the bladder—may perhaps be said to vary from 175–250 cc. (6–9 fl. oz.), 700 cc. (24 fl. oz.) representing the maximum for the normal organ (Disse). Under pathological conditions, as in paralysis of the vesical wall, the bladder may contain from 3–4 litres without rupture. As a means of determining its capacity during life, estimates based upon artificial distention of the bladder after death are worthless, since the maximum resistance

without rupture of the dead vesical wall is much less than that of the living organ. The bladder in the female has a smaller capacity than in the male.

The **interior of the bladder** varies in appearance according to the condition of the mucous membrane. The latter is loosely attached to the muscular tunic by submucous areolar tissue, and hence in the contracted state of the organ is thrown into conspicuous, mostly longitudinal plications; when the bladder is filled these folds are effaced and the inner surface appears smooth. With excessive distention, the interlacing bundles of the muscular wall may be stretched so far apart that the submucous tissue and the mucosa may occupy the interstices so formed, an irregular pitting or pouching of the mucous lining resulting. A triangular area, the *trigonum vesicæ*, included between the urethral orifice in front and the ureteral openings behind, is distinguished by its smoothness under all degrees of contraction, even in the empty bladder being only indistinctly wrinkled. Over the trigone (Fig. 1620) the submucosa is absent and the mucous membrane rests directly upon a compact muscular stratum in which the closely placed transverse bundles of the vesical wall are reinforced by radiating fibres continued from the ureteral sheath (page 1897). The slightly curved posterior border or base of the trigonum is marked by a band-like elevation, the *plica uretericæ*, or *torus uretericus* of Waldeyer, that unites the openings of the renal ducts. This ridge, best marked at its outer ends, is less evident and often interrupted near the mid-line, and is subject to much individual variation. Its production depends upon the elevation of the mucosa and muscular tissue in consequence of the oblique path of the ureters through the vesical wall. The margins of the trigonum—lateral as well as posterior—are raised and its central area is somewhat depressed towards the *urethral opening*. The latter (**orificium urethrae internum**) occupies the apex of the trigonum, and is usually not circular, but crescentic, owing to the projection of its posterior border as a small median elevation, the *vesical crest* (**uvula vesicae**), that extends from the apical end of the trigone into the urethra to become continuous with the urethral crest in the prostatic part of the canal. The vesical crest consists of a thickening of the mucous membrane enclosing bundles of muscular tissue. When hypertrophied, as it not infrequently is in aged subjects, this fold may form a valvular mass that occludes the urethral orifice. The anterior wall of the latter is commonly marked by low converging folds continuous with the longitudinal plications of the urethral mucous membrane.

FIG. 1620.



Interior of lower segment of partly distended and hardened bladder, viewed from above and behind.

The *ureteral orifices* are usually slit-like in form (4–5 mm. long), obliquely transverse in direction, but may be oval, round, or punctiform (Disse). The lateral border of the opening is guarded by a valve-like projection (**valvula ureteris**) that forms part of the nodular elevation that is produced by the wall of the ureter. The median margin of the opening is embedded in the interureteral plica. The urethral and the two ureteral openings mark the angles of an approximately equilateral triangle, the sides of which, in the contracted condition of the bladder, measure from 2–2.5 cm.; when the organ is expanded, this distance increases to from 3.5–5 cm. or even more. The urethral orifice lies from 1.75–2.2 cm. in front of the base of the trigone when the latter is contracted. Immediately behind the vesical triangle the posterior bladder-wall presents a slight depression, the *retrotrigonal fossa* or *fovea retrouréterica* (Waldeyer), that corresponds to the "bas-fond" of the French writers. When abnormally enlarged and pouch-like, as it often is in advanced life when associated with an enlarged prostate, this fossa becomes of practical importance (page 1981).

Peritoneal Relations.—The superior surface of the empty or but slightly filled bladder is completely covered by peritoneum as far as the lateral and posterior

borders. On each side the serous covering passes from the organ to line the para-vesical fossa, the sickle-shaped depression that separates the contracted bladder from the adjacent pelvic wall. In front these side folds, the *lateral false ligaments*, meet at the vesical apex, where they cover the fibrous band of the urachus and are reflected onto the anterior abdominal wall as the *anterior false ligament* (**ligamentum umbilicale medium**). An uncertain fold, the *plica vesicalis transversa*, often crosses the otherwise smooth upper surface of the bladder. This peritoneal ridge, sometimes represented by two or more low wrinkles, extends laterally to be lost either on the pelvic wall or, passing over the pelvic brim, towards the internal abdominal ring. Dixon[1] found the fold well represented in the male fœtus, and inclines to the view that its production is connected with a drag on the peritoneum incident to the formation of the inguinal pouches. Behind the peritoneum passes from the posterior border of the empty bladder over the upper end of the seminal vesicles and the vasa deferentia, to form a horizontal crescentic shelf-like fold (**plica rectovesicalis**) from 1–1.5 cm. wide, that extends from the bladder backward, embracing the rectum and ending at the sacrum on either side of the gut (Fig. 1619).

Since this duplicature includes parts of the seminal ducts and vesicles, Dixon and Birmingham[2] have suggested for its lateral and backward extensions, which contain bundles of involuntary muscle (**m. rectovesicalis**) attached to the sacrum and rectum, the appropriate name, *sacro-genital folds*, and pointed out their correspondence to the utero-sacral folds in the female (page 2007). The median part of the shelf-like plica, conspicuous behind the empty bladder, but more or less obliterated on the distended organ, overhangs the lowest part of the peritoneal recess, the *recto-vesical fossa*, that intervenes between the rectum and the seminal vesicles and ampullæ of the vasa deferentia, and towards which the fundus of the bladder is directed. In recognition of these relations, the anterior wall of this recess being in direct relation with the seminal tracts, the authors last mentioned propose to call this depression the *recto-genital fossa*,—a term alike applicable to both sexes, since the relations of the rectum to the uterus in the pouch of Douglas in the female are similar. All other parts of the bladder, including the postero-inferior (fundus) and the antero-inferior surfaces, are entirely devoid of peritoneal covering. In the female the serous membrane passes from the posterior border of the bladder onto the anterior uterine wall, the shallow *utero-vesical fossa* intervening. Occasionally a corresponding depression exists in the male as a slight indentation between the posterior vesical wall and the seminal vesicles (Dixon).

With the changes of form and position which the bladder undergoes when it becomes distended are associated alterations in its peritoneal relations. These include the gradual obliteration of the upper part of the recto-vesical fossa, along with the shelf-like fold, and the elevation of the line of peritoneal reflection at the sides, so that the lateral false ligaments no longer reach the pelvic floor, but pass from the lateral wall of the pelvis directly to the superior surface of the bladder, from which the plica transversa has disappeared. Anteriorly the relations of the serous covering are also affected, since with the rise of the bladder above the level of the symphysis the peritoneum is carried upward and a suprapubic non-peritoneal area becomes progressively more extensive until, in extreme distention, a space measuring vertically from 8–9 cm., or about 3¼ in., may be uncovered.

Fixation.—The attachments of an organ so subject to considerable alterations in size and form as is the bladder must obviously provide for such changes as well as the maintenance of a more or less definite position. The "ligaments" of the bladder are conventionally described as *true* and *false*, under the latter being included the peritoneal folds (above described) that pass from the organ to the adjacent abdominal and pelvic walls. The sacro-genital folds were formerly sometimes called the *posterior false ligaments*. From the manifest instability of the relations and attachments of the peritoneum incident to distention and contraction, it is evident that such peritoneal folds can contribute little to the definite support or fixation of the bladder; hence those parts of the organ possessing a serous covering are movable. The inferior surface, on the contrary, is comparatively fixed on account of its close relations to the pelvic floor (and in the male to the prostate) and the presence of fascial bands or *true ligaments*. The latter are derived from the pelvic fascia, which in the vicinity of the bladder presents a stout, glistening, band-like thickening (**arcus tendineus**) that on each side stretches from the posterior surface of the symphysis, a

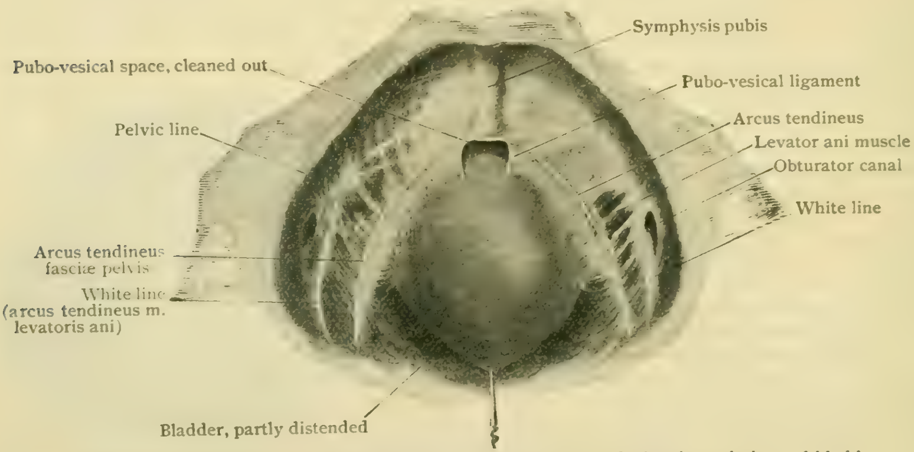
[1] Journal of Anatomy and Physiology, vol. xxxiv., 1900.
[2] Journal of Anatomy and Physiology, vol. xxxvi., 1902.

short distance above its lower border, backward to the ischial spine (page 1899). On either side of the mid-line the anterior ends of these tendinous arches pass as strong fascial bands, the *pubo-prostatic ligaments*, from the symphysis to the prostate, blending with its capsule, and thence continue to the inferior surface of the bladder, where they are lost in the outer fibrous coat of the vesical wall. In the female these fascial bands pass directly to the bladder as the *anterior true ligaments*. After leaving the symphysis, the tendinous arches send expansions—the *lateral true ligaments*—to the side of the bladder, which materially assist in fixing the organ.

The cleft left between the medial borders of the two levator ani muscles is occupied in the male by the rectum and prostate and in the female by the rectum, vagina, and urethra, over some of which organs (rectum, vagina, and prostate) the pelvic fascia covering the upper surface of the levator ani muscles (**fascia diaphragma pelvis superior**) sends more or less extensive investments and thus binds them to the pelvic floor.

Additional support is afforded by more or less definite processes of muscular tissue prolonged from the bladder to adjacent structures; those passing within the arcus tendineus to be attached on either side to the back of the symphysis constitute the *pubo-vesical muscles*, while others, the *recto-vesical muscles*, extend backward to blend with the rectal wall.

FIG. 1621.



Anterior part of pelvis of female, viewed from above and behind, showing relations of bladder to pelvic fascia; bladder has been partly distended and pulled backward.

Between the lateral pubo-prostatic ligaments, the symphysis, and the bladder lies a deep recess (**fovea pubovesicalis**), traversed by the dorsal vein of the penis and filled with fatty areolar tissue, the floor of which is formed by the fusion of the pelvic fascia with the transverse ligament of the perineum. Above the level of the pubo-prostatic ligaments lies the *prevesical space*, or *space of Retzius*, which is bounded in front by the anterior wall of the pelvis below and the transversalis fascia above, and behind by a thin membranous condensation of areolar tissue, the *fascia umbilico-vesicalis* (Farabeuf), that passes from the pelvic floor over the prostate and bladder to the abdominal wall, to fuse with the transversalis fascia at a variable distance below the umbilicus. Laterally the boundaries of this space, filled with areolar tissue loaded with fat, are uncertain, since when distended, as when the seat of an abscess, it may embrace the sides of the bladder below and extend above as far as the obliterated hypogastric arteries. Under usual conditions, however, the space may be regarded as confined chiefly between the antero-inferior surface of the bladder and the adjacent anterior pelvic wall.

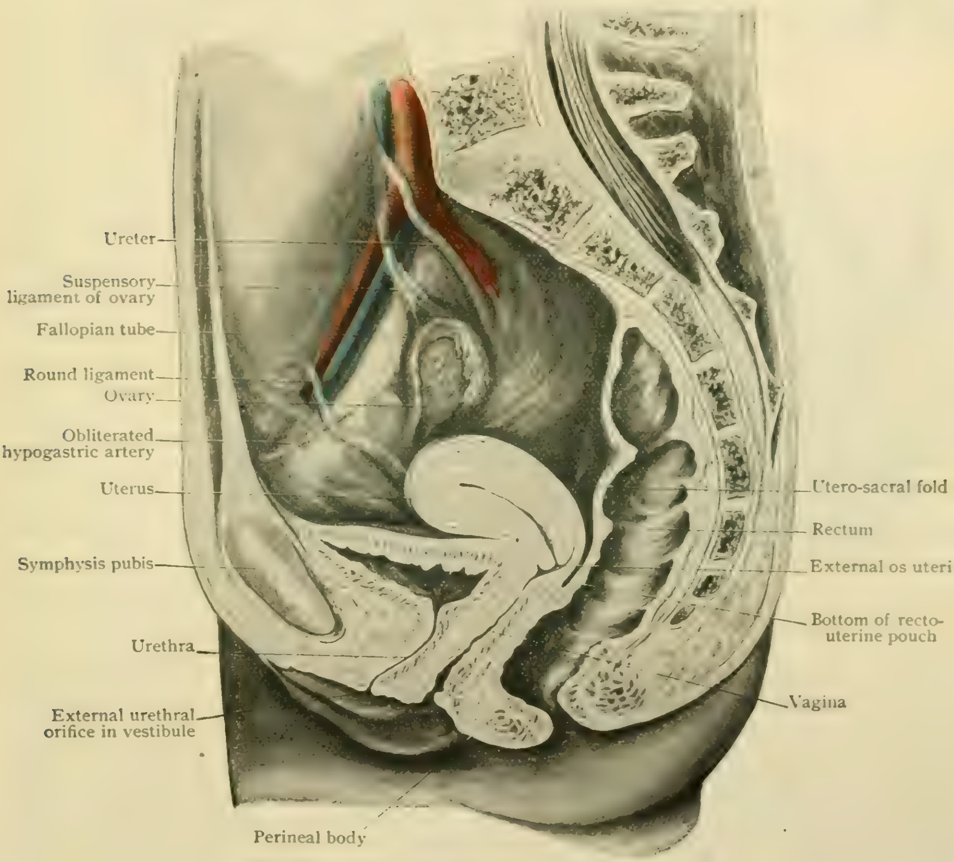
Relations.—When empty, or containing only a small quantity of fluid, the bladder possesses two general surfaces, a superior and an inferior. The anterior two-thirds of the the latter rests upon the prostate and the pelvic floor, and, according to Dixon,[1] when hardened *in situ* presents a rounded median ridge which, together with the ureters, outlines two forward, upward, and outward sloping infero-lateral areas. These rest upon the pelvic floor and the posterior surface of the pubis, separated

[1] Journal of Anatomy and Physiology, vol. xxxiv., 1900.

from the latter by the retropubic pad of fat from .5–1 cm. thick. The fundus—the posterior part of the inferior surface included between the urethral opening and the posterior border—is in contact with the median ends of the seminal vesicles and of the ampullæ of the seminal ducts, by which structures and their musculo-adipose bed the bladder is separated from the anterior wall of the recto-vesical fossa.

The *internal orifice of the urethra* lies immediately above the prostate, usually from 1.2–2.5 cm. (½–1 in.) above the plane passing through the lower border of the symphysis and the lower end of the sacrum; the distance from the upper border of the symphysis to the orifice measures from 5–6 cm. (2–2½ in.); in the horizontal plane it lies from 2.5–3 cm. behind the symphysis, its nearest point on the latter being about 2 cm. (Disse). These measurements are influenced by changes in the position of the inferior surface, being shortest when the empty bladder is pushed upward.

FIG. 1622.



Sagittal section of female pelvis of formalin subject.

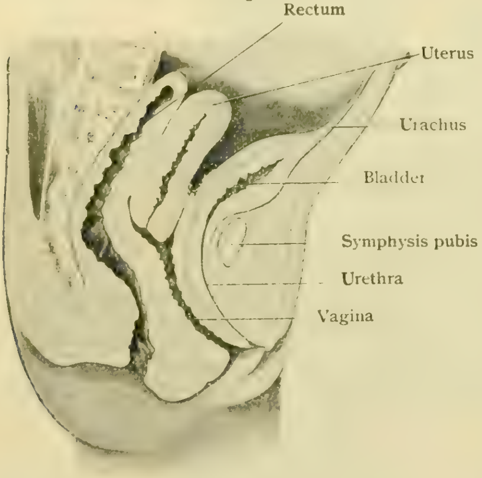
Laterally the *paravesical fossæ* intervene between the empty bladder and the sides of the pelvis. In the contracted condition the superior surface usually lies below the plane of the pelvic inlet, the entire bladder being within the anterior third of the pelvis and close to the pelvic floor. This upper surface, covered with peritoneum, is in contact with coils of small intestine which, when the rectum is empty, may occupy a part of the recto-vesical fossa.

In the **distended bladder** the relations of the inferior surface suffer little change on account of the intimate attachments of the vesical wall to the prostate and to the fixation to the pubis afforded by the pubo-prostatic (pubo-vesical) ligaments and enclosed muscle. The postero-inferior surface expanding backward and outward, comes into more extensive and closer rela-

tions with the seminal vesicles and ducts. The condition of the rectum markedly influences the degree to which the distending bladder rises above the symphysis, since, when the bowel is empty, and hence more intrapelvic space is available, the bladder gains a lower suprapubic level than when its ascent is favored by a distended rectum. With the elevation of the vesical apex above the level of the symphysis, the bladder acquires a temporary relation with the anterior abdominal wall in front, and its sides, in case of marked distention, may come nearly or actually into contact with the vasa deferentia, the obliterated hypogastric arteries, and the obturator vessels and nerves, as these structures lie along the pelvic wall embedded within the fat-laden subperitoneal tissue.

The **bladder in the female** lies lower within the pelvis than in the male, chiefly in consequence of the absence of the prostate, and when empty never quite reaches the level of the upper border of the symphysis. When distended, therefore, it less often rises into the abdomen, since the capacity of the normal organ in the female is somewhat less than in the male. The fundus, or postero-inferior surface, is firmly united by connective tissue with the anterior vaginal wall and sometimes the lower part of the uterus. Where reflected from the anterior surface of the uterus onto the bladder, the peritoneum lines the shallow utero-vesical fossa and then continues over the superior vesical surface. Upon the latter rests the body of the uterus, rising or falling with the expansion or contraction of the bladder-wall, but normally remaining in contact, —a relation predisposing to the production of the concave or sunken condition of the superior surface not infrequently seen in frozen sections of the female pelvis.

FIG. 1623.



Sagittal section through pelvis of new-born female child, hardened in formalin, showing infantile form and suprapubic position of bladder.

The **infantile bladder** differs both in form and position from the adult organ. Since the greater part of the bladder represents a persistent and dilated portion of the intra-embryonic segment of the allantois, its fœtal form is essentially tubular. In the new-born child (Fig. 1623), in both sexes alike, the bladder is spindle-shaped and extends from about midway between the umbilicus and the symphysis to the level of the pelvic brim, its anterior surface being in contact with the abdominal wall. Only the lower pole of the infantile bladder, corresponding to the urethral orifice, lies slightly below the upper border of the symphysis, the body lying entirely within the abdomen, lateral and posterior surfaces being undifferentiated. Leaving the anterior abdominal wall, the peritoneum completely invests the posterior surface of the bladder, as well as the seminal vesicles and the ampullæ of the seminal ducts, before passing onto the rectum. The bottom of the recto-vesical fossa lies often below the level of the urethral orifice, which does not come into relation with the pelvic floor. In the new-born female child the uterus is situated relatively high and comes into contact with the bladder, while the vagina does not, only touching the urethra. The reflection of the peritoneum to form the utero-vesical fossa varies in position, and when high, as it often is, may leave a part of the young bladder unprovided with a serous covering. Coincident with the descent of the bladder, associated with the growth and expansion of the pelvis, its posterior wall increases more rapidly than the anterior, this inequality resulting in the production of a fundus that gradually approaches the pelvic floor. According to Disse,[1] the descent of the young bladder is rapid during the first three years, slower from the fourth to the ninth year, between which and puberty little change occurs. Succeeding this period of rest the bladder renews its descent, and by the twenty-first year has gained its definite position on the pelvic floor. Before the third year the empty bladder always remains above the symphysis; by the ninth year it has sunken below that level, but when distended the apex rises within the abdomen. During descent the non-peritoneal area on the posterior surface progressively increases, the serous investment in general extending farther downward in the male than in the female child. Persistence of infantile relations often accounts for variations observed in the adult.

Structure.—The bladder consists essentially of a muscular sac lined with mucous membrane and covered on its upper surface with peritoneum, a layer of connective tissue loosely uniting the mucous and muscular coats. From within outward, four coats

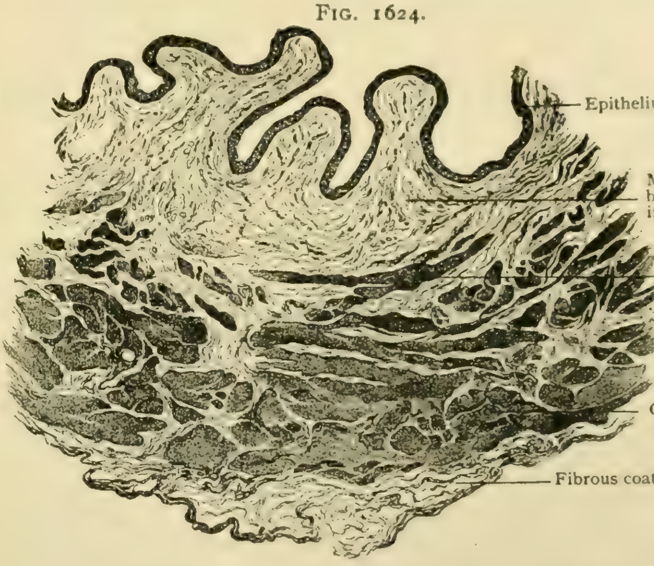
[1] Anatomische Hefte, Bd. i., 1892.

are distinguishable,—the mucous, the submucous, the muscular, and the incomplete serous.

The *mucous coat* varies in thickness with both location and the degree of contraction. Over the vesical trigone, where always comparatively smooth, it is thin, measuring only about .1 mm.; where strongly wrinkled by contraction, it may attain a thickness of over 2 mm. The mucosa resembles closely that of the renal duct, consisting of a fibro-elastic tunica propria covered with transitional epithelium. The latter includes several strata of cells, the deepest of which are columnar, the middle irregularly polygonal or club-shaped, and the inner plate-like, their deeper surface fitting over and between the underlying elements. Although glands may be considered as absent, tubular depressions are occasionally found in the vicinity of the trigone which are regarded by some (Kalischer, Brunn) as true glands. Waldeyer has suggested that these structures may be interpreted as representing in a sense urethral glands displaced during the development of the vesical trigone.

The *submucous coat*, loose and elastic, permits free gliding of the mucous over the muscular tunic when readjustment becomes necessary during contraction. Composed of bundles of fibrous tissue interwoven with elastic fibres, it supports the blood-vessels and nerve-plexuses, and contains numerous bundles of involuntary muscle. It is not sharply defined from the adjoining coats, but blends with the stroma of the mucosa on the one side and extends between the tracts of the muscular coat on the other. Beneath the trigonum a distinct submucous layer is wanting or replaced by a sheet of muscular tissue.

Fig. 1624.



Section of wall of bladder, under very low magnification, showing general disposition of coats. × 12.

The *muscular coat*, thicker than the mucosa and comparatively robust, varies according to the condition of the bladder, being thin during distention and very thick in strong contraction, when it may measure as much as 1.5 cm. The bundles of involuntary muscle are arranged in two fairly distinct chief layers,—a thin outer longitudinal and a thick inner circular. Inside the latter, and virtually within the submucosa, lies an incomplete additional layer. The longitudinal bundles, best developed on the upper and lower surfaces, do not constitute a continuous sheet, but interlace, leaving interfascicular intervals which are occupied by connective tissue. In the vicinity of the prostate extensions of the outer layer are attached to the anterior pelvic wall as the pubo-vesical muscles; others pass backward to blend with the intestinal wall as the recto-vesical muscles, while from the apex bundles are prolonged into the urachus. The circular layer, although more robust and uniform than the outer, is weak and imperfect over the trigonal region, and in both sexes is well developed only after attaining the level of the internal ureteral orifices (Disse). Towards the apex of the bladder the bundles of the circular layer assume an oblique and less regular disposition. The innermost layer—that within the submucosa—is represented by isolated and indefinite muscular bundles that are blended with the connective tissue. Over

the vesical trigone, however, this layer becomes condensed and forms a compact transverse muscular sheet that is closely united to the overlying mucous membrane and, in conjunction with the muscular tissue of the urethra, surrounds the beginning of that canal with a constrictor-like tract, the *internal vesical sphincter.*

The outer *fibrous coat* of the vesical wall is strongest over the inferior surface, where it receives reflections from the pelvic fascia; towards the apex and beneath the peritoneum it is less definite and often intermingled with adipose tissue. Over the postero-inferior surface in the male it is fused with the fibrous tissue surrounding the seminal vesicles and ducts, and in the female is blended with the anterior vaginal wall.

Vessels.—The *arteries* supplying the bladder are chiefly the superior and inferior vesical, from the anterior division of the internal iliac ; these are reinforced by branches from the middle hemorrhoidal, as well as by small twigs from the internal pudic and the obturator arteries. The superior vesical supplies the upper segment of the bladder and sends small branches along the urachus. The inferior vesical divides into two or more branches which are distributed to the infero-lateral and postero-inferior surfaces. In addition to twigs to the region of the trigone, others pass to the prostate, seminal vesicles, and ducts. On gaining the bladder, the vesical branches anastomose and enclose that organ in an arterial net-work from which twigs enter the muscular coat and break up into capillaries for its supply. Others penetrate the muscular tunic and within the submucosa form a net-work from which arterioles pass inward for the supply of the mucous membrane.

The *veins* do not accompany the arteries, but form a submucous plexus that drains the mucous membrane and empties into a muscular plexus which, in turn, is received by an external subperitoneal plexus. From the latter the blood from the entire organ passes into the large prostatico-vesical plexus at the sides of the bladder and thence into the tributaries of the internal iliac veins. With the exception of the smaller ones on the inferior surface, all the vesical veins possess valves (Fenwick).

The *lymphatics* of the bladder begin as a close-meshed net-work within the muscular coat, according to Gerota,[1] being absent within the mucous membrane. Outside the muscular coat they form a wide-meshed subperitoneal plexus, those from the apex and body coursing downward and laterally and those from the fundus upward. Leaving the sides of the bladder, the efferent channels, chiefly in company with the arteries, pass to the internal iliac lymph-nodes and to those situated at the bifurcation of the aorta. Along the path of the lymphatics on the antero-inferior surface of the bladder Gerota describes one or two very small nodes as usually present.

The **nerves** of the bladder include both sympathetic and spinal fibres. The former, distributed chiefly to the muscular tissue, are from the vesical plexuses, which, as subordinate divisions of the pelvic plexuses, lie at the sides of the bladder. The sympathetic fibres accompany the arteries and are joined by the vesical branches from the sacral plexus derived from the third and fourth, possibly also the second, sacral spinal nerves. The principal trunks reach the bladder in the vicinity of the ureters, the trigonal region receiving the most generous nerve-supply and the apical segment the fewest fibres. Within the outer fibrous coat the larger nerves divide into smaller branches that are connected with ganglia, especially in the neighborhood of the ureters, from which twigs enter the muscular tunic and break up into smaller ones bearing terminal microscopic ganglia before ending in the muscle. Other branches penetrate the submucosa, where they form plexiform enlargements containing numerous minute ganglia, from which fine twigs proceed to the mucosa to end, according to Retzius, between the epithelial cells. In general the sensibility of the normal bladder is comparatively slight, the trigonal region, especially at the ureteral openings, being its most sensitive area.

PRACTICAL CONSIDERATIONS: THE BLADDER.

Absence of the bladder is a very rare abnormality, but in more than one case has proved to be consistent with prolonged life, the dilated ureters—opening into the urethra—having acted as reservoirs for the urine and the muscle-fibres at their constricted orifices having taken on sphincteric action and prevented urinary incon-

[1] Anatom. Anzeiger, Bd. xii., 1896.

tinence. In other less fortunate cases in which the ureteral openings were on the surface of the body, implantation of the ureters into the intestinal tract (page 1901) has been done with varying degrees of success.

Extroversion (exstrophy) of the bladder, the most frequent congenital abnormality of this organ, is associated with failure of the ventral plates forming the abdominal wall to unite in the mid-line. In this condition, which occurs in males in from 80 to 90 per cent. of cases, the symphysis pubis and the anterior wall of the bladder frequently are also lacking, and the posterior vesical wall—protruded by intra-abdominal pressure—forms a rounded prominence, deep red in color, from chronic congestion. The ureteral orifices are often plainly visible. Cryptorchism, bifid scrotum, inguinal hernia, and epispadias are frequently present. Although the opinions regarding the causes and factors leading to these malformations are various and conflicting, it is certain that these defects depend upon faulty development at a very early period of fœtal life, probably in connection with abnormalities of the allantois and of the cloacal region of the embryo, and that the suggested explanations on a mechanical basis, as over-distention of the allantois or unusual shortness or location of the umbilical cord, are entirely inadequate to account for malformations which often so profoundly affect the entire lower segment of the anterior body-wall and the associated organs.

Occasionally a *vesico-abdominal fissure* occurs without extroversion, when the posterior wall of the bladder will be concave instead of convex and partially covered by the imperfect abdominal wall.

The posterior wall of the bladder and the anterior wall of the rectum or vagina may be defective at birth, resulting in a congenital vesico-rectal or vesico-vaginal fistula.

The fœtal communication between the extra- and intra-abdominal portions of the allantoic sac may remain pervious, so that the urachus, instead of becoming a fibrous cord extending from the umbilicus to the summit of the bladder, is patent and constitutes a channel by means of which urine is discharged at the navel.

Cystocele.—A portion of the bladder may be found either alone or together with intestine or omentum in the sac of an inguinal or femoral hernia, or more rarely it may be part of an obturator or perineal or ventral hernia.

The ordinary causes of abdominal hernia (page 1759) favor the production of this condition. In their presence, and especially if there is also present an intestinal hernia of long standing, a thinned and dilated bladder may readily be drawn by gravity into one of the hernial orifices by the connection of its extraperitoneal portion with the subperitoneal fat with which it is in close contact. The bladder "diverticulum," thus formed, is a result, not a cause of the hernia, and in 75 per cent. of cases includes only the extraperitoneal bladder-wall. As vesical dilatation and atony are usually the result of obstructive disease,—most common in elderly males,—and as abdominal hernia is frequent during late middle life (page 1762), it will be understood why 75 per cent. of cases of hernia of the bladder occur in men (irrespective of cases of vaginal cystocele) and more than 50 per cent. in persons over fifty years of age. In old herniæ there has, of course, been an opportunity for the stretching and elongation of the bladder-wall essential for the production of the cystocele.

The laxity of the attachments of the bladder to surrounding structures necessitated by its changes in size or capacity favors the production of hernia.

Effects of Distention.—The cavity of the normal empty bladder, which is strongly contracted during life, presents little more than a narrow, cleft-like lumen, with a gentle upward curve, continuous with that of the urethra. As it distends the pyriform bladder becomes oval in shape, its summit rises from the pelvis above the symphysis pubis, its anterior wall becomes applied to the inner surface of the abdominal wall in the hypogastric region, and the whole organ assumes an ovoid shape or, in extreme distention, one nearly spherical. Its normal capacity in the adult is about one pint, but the looseness of the submucosa over the greater part of its surface, the reticular arrangement of its muscle-fibres, and the yielding nature of the structures by which it is surrounded when it has risen from the pelvis permit of its enormous distention, especially as a result of slowly increasing obstructive dis-

ease. Its summit may then pass above the level of the umbilicus and it may fill almost the whole abdomen.

Retention of urine—inability to empty the bladder—may be due (*a*) to obstruction at the neck of the bladder, the prostate, or the urethra, as from clots in bleeding from the kidneys, ureters, or the bladder itself, prostatic hypertrophy, stricture, or rupture of the urethra; (*b*) to affections of the bladder muscles, as paresis or paralysis of the detrusors in cerebral or spinal injury or disease, or reflex spasm of the sphincter after operations on the anus or rectum; or incoördination, as in hysteria, or neurasthenia, or shock.

The distended bladder forms a rounded fluctuating tumor in the hypogastric region, which, as the intestines are pushed up with the fold of peritoneum back of the urachus (plica vesico-umbilicalis), is always dull on percussion. If the distention is acute, the pressure on the sensory nerves of the bladder gives rise to distressing pain. If it takes place slowly, or if it follows cerebral or spinal injury, it may be quite painless.

After a time, in cases of great distention, the sphincter vesicæ and compressor urethræ yield to the pressure and the urine overflows the bladder more or less continuously,—incontinence of retention,—a condition which should always be suspected to exist in aged male patients who have either very frequent urination or constant urinary dribbling. Great paresis or actual paralysis of the detrusors may result from distention, so that the power to empty the bladder is temporarily or permanently lost even after all obstruction has been removed.

During marked distention certain changes take place in its relations that are of much practical importance. The neck of the bladder is so firmly fixed in position by the base of the prostate, with its dense capsule continuous with the deep layer of the triangular ligament (page 1977), by the anterior true ligaments of the bladder itself, and by its close attachment to the rectum or to the uterus and vagina, that it does not participate in the upward movement of the summit and body, but if the rectum is not distended, rather sinks slightly in the pelvis. The looseness of the fatty connective tissue occupying the space of Retzius (page 1906) and separating the antero-lateral walls of the bladder below the peritoneal reflection from the pubes and the obturator internus and levator ani muscles permits the elevation, during distention, of all the remainder of the bladder.

The anterior peritoneal fold, which, with the bladder undistended, reaches to the symphysis pubis, is so raised that if the summit of the bladder is half-way between the pubes and the umbilicus, there will be from 5–6.5 cm. (2–2½ in.) of the non-peritoneal portion of the anterior bladder-wall in close apposition with a similar area of the inner surface of the abdominal wall. In a male child five years of age the space between the upper edge of the symphysis pubis and the reflection of the peritoneum will be one inch when the bladder contains three ounces of liquid. The close attachment of the peritoneum to the summit of the bladder and its very loose attachment to the parietes (necessitated by the changes in size and position of the bladder) permit this upward displacement.

Coincident distention of the rectum by a rubber bag limits the backward and downward extension of the distended bladder, adds slightly to its elevation in the abdomen, keeps it in close contact with the abdominal parietes, and increases the distance between the recto-vesical fold and the anus from two and a half inches to three and a half inches. The use of the rectal bag has practical disadvantages which have led to its abandonment in most cases. The Trendelenburg position elevates the partly distended bladder and carries upward the peritoneal folds by gravity. Various operations (*vide infra*) are so planned as to take advantage of this uncovering of the bladder-wall, which permits access to that viscus and to its cavity without danger of peritoneal infection.

Prevesical inflammation may follow infection through an operation or other wound, involving the prevesical space of Retzius, or may be caused by extravasation of urine into that space; and as the connective tissue occupying it is continuous superiorly with the abdominal and inferiorly with the pelvic extraperitoneal tissue, a cellulitis beginning there may be widespread, or may result fatally. Some of the relations of this space are indicated in the fact that such infection has been known to

follow chronic cystitis, uterine or periuterine inflammation, post-partum suppuration of the symphysis pubis, and purulent thrombosis of the umbilical vein in a new-born infant (Thorndike).

Collections of pus have opened from here spontaneously through the anterior abdominal wall, into the rectum, the bladder, or the urethra, and into the peritoneal cavity.

Rupture of the bladder rarely follows distention alone, but is not uncommon as a result of trauma expended upon the pelvis or lower abdomen when the bladder is distended. The cases in which rupture follows over-distention from obstructive disease, without the intervention of force, are usually prostatic in origin, as in retention from stricture the urethra ordinarily ulcerates behind the constriction and periurethral extravasation of urine relieves the tension.

The liability to traumatic rupture is directly proportionate to the degree of distention and consequent elevation of the viscus, and if that condition exists in a bladder the subject of chronic dilatation and atrophy, or in one rendered unnaturally immobile by pericystitis or pelvic cellulitis, the force required to produce rupture is much lessened. Occasionally in the presence of fracture of the pelvis it is difficult to decide whether a given lesion of the bladder is a rupture or a wound from a fragment of bone.

Eighty-five per cent. of ruptures are *intraperitoneal*, because, (*a*) in distention the peritoneal becomes the most tense of the coats of the bladder-wall; (*b*) it is the least elastic; (*c*) it covers that portion of the bladder which, as it rises into the abdomen, first loses the protection afforded by the pelvis, and is less reinforced by pressure from surrounding tissues; (*d*) the bladder-walls are thinnest over that area; (*e*) the region is exposed to counter-pressure against the promontory of the sacrum. These conditions also explain the usual situation of intraperitoneal ruptures in the upper and posterior bladder-wall.

Extraperitoneal rupture is apt to be in the anterior wall,—*i.e.*, that portion most immediately in contact with the pelvic bones, which in these cases are often found to be fractured.

Pathological (spontaneous) rupture is usually in the extraperitoneal portion of the bladder, because there the influence of gravity is most potent in aiding in the production of the protrusion of the thinned mucosa between the often hypertrophied bands of muscular fibres. The early stage of this condition—in which the muscle hypertrophy is the prominent change—constitutes the so-called *fasciculated bladder*; later, when the pouching has become marked, it is known as *sacculated bladder*.

In children rupture of the bladder is rare in spite of its thinness and of the fact that in them it is an abdominal rather than a pelvic organ, because (*a*) the chief causes of distention are absent; (*b*) the greater sensibility of the bladder renders its evacuation more frequent or less likely to be neglected; in the adult incontinence of urine generally means distention, in the child irritation (Owen); (*c*) owing to the undeveloped condition of the prostate the bladder is more movable.

Wounds of the bladder may occur from within,—during instrumentation,—or the bladder may be reached by weapons, missiles, or vulnerating bodies of any sort, through the suprapubic region, the rectum, the perineum, the obturator or the sciatic foramen. They often result from the direct laceration of the bladder-wall by a bony fragment in fracture of the pelvis. Like ruptures, they may or may not involve the peritoneum.

The *symptoms* of rupture or wound will obviously vary with the situation of the lesion. The most important are due to the escape of urine from the bladder either into the space of Retzius or into the peritoneal cavity. The determination of the general character of the injury—made in part by catheterization, which, in the presence of inability to urinate, yet fails to draw more than a little bloody urine, and does not withdraw all of a measured quantity of injected fluid—should be followed by instant operation, whether the lesion is extra- or intraperitoneal in its situation.

Occasionally, after a small stab or pistol wound, the loose mucosa may act as a plug, and, aided by the muscular contraction of the bladder-wall, will for a time prevent extravasation, and then the above-mentioned signs may be absent or may appear later, when ulcerative or necrotic processes have opened the way for the

escape of urine. A similar, but usually permanent closure of the wound—by muscular contraction, or by a valvular action from the change in the relation of the coats of the vesical wall after tension has been relieved—takes place when the bladder has been tapped above the pubes (*suprapubic puncture*).

Cystitis, in so far as it has an anatomical bearing, should be studied with regard to the possible sources of the essential infection and of the almost equally essential predisposing condition of congestion. No explanation is required of the influence of (*a*) frequent micturition, however caused ; (*b*) trauma ; (*c*) vesical distention ; (*d*) acid urine ; (*e*) calculi or tumors ; (*f*) cold and wet ; (*g*) prolonged sexual excitement ; (*h*) cardiac weakness, in bringing about a congestion of the vesical and vesico-prostatic plexuses. The sudden removal of pressure when an habitually distended bladder is emptied may be followed by congestion so excessive as to cause hæmaturia.

Infection may occur by spreading from the urethra or prostate, by instrumentation, by descent from the kidneys, by extension from any pericystic focus of suppuration, or by direct passage of the microbic cause from the rectum. The great venous plexus at the base of the bladder, emptying into the valveless internal iliac veins, is engorged whenever pressure is made upon the latter, as by fecal masses in the sigmoid flexure or rectum. Constipation is thus both a predisposing and—through the migration of microbes to the contiguous bladder—an exciting cause of cystitis.

The mucosa of the bladder, supplied by the hypogastric plexus, is not very sensitive normally, except in the region of the trigonum. There it is tightly connected with the muscular layer, and the loose, elastic, submucous connective tissue found in the remainder of the bladder is absent. The difference is shown by the smooth surface of the trigonum as contrasted with the rugæ of the lax mucosa seen over the rest of the interior of the empty bladder. The laxity in the superior portions of the bladder is determined by the necessity for great changes in its size. At the trigonum a similar looseness of the mucosa would encourage its prolapse, and might result in frequent obstruction of the ureteral and vesical outlets. This close adhesion of mucous and muscular layers prevents free swelling when inflammation occurs, and, in conjunction with the particularly generous vascular and nerve-supply to the trigonum and neck of the bladder, explains the pain and sensitiveness of that region in cystitis. In a marked case the whole bladder may become sensitive, so that hypogastric pressure is painful.

Frequent micturition, as a result of cystitis or of other conditions in which vesical irritation is present, is due to stimulus of the sensory nerves supplied by the third and fourth sacral nerves from the second, third, and fourth sacral segments of the cord. The motor impulse reaches the bladder from the eleventh and twelfth dorsal and first lumbar segments through the hypogastric and pelvic plexuses.

The skin of the scrotum and of the penis and the urethral mucous membrane are supplied with sensation from the same spinal segments as is the bladder, and therefore the referred pains in vesical irritation or inflammation are often felt in those regions in the distribution of the perineal branches of the pudic and inferior gluteal nerves. As the inferior hemorrhoidal nerve—supplying the skin over the external sphincter ani and about the anus—is often derived from the sacral plexus, itching or tickling in that region or painful spasm of the anal sphincter may be caused by vesical irritation.

Other referred pains in vesical disease are to the lumbo-sacral region, through the communication between the second, third, and fourth sacral nerves and the hypogastric plexus ; to the kidney, by the junction in the spermatic plexus of filaments from the vesical and renal plexuses ; and to the lower limb, occasionally to the foot (pododynia), through the sacral nerves which enter into the sacral plexus and the lumbo-sacral cord, giving off the great sciatic nerve, and also into the pelvic plexuses.

The important muscular element in the vesical, as in the ureteral, walls gives the "colicky" character to the symptoms of irritation and, in the case of the inflamed bladder, causes the violent tenesmus accompanying the discharge of the last drops of urine, when the muscles in the vicinity of the sensitive trigonum contract spasmodically.

The same symptoms—frequent micturition, referred pains, tenesmus—are caused by a *vesical calculus* and have the same anatomical basis. They are most marked if the stone is small, rough, and movable, so that in the erect position it falls upon the trigonal surface. Such a stone may roll or be forced by the stream of urine into the vesical outlet and produce sudden interruption of micturition. This symptom is seen most often in young male children, in whom the relatively vertical position of the bladder, the marked tenesmus caused by the presence of the stone, and the small size of the vesical orifice favor its production. The tenesmus in children is often so excessive as to result in prolapse of the rectum, which is affected by and participates in the straining expulsive efforts.

In a sacculated bladder a very large stone may lie in a pouch with but little of its surface presenting towards the bladder-cavity (encysted stone) and give rise to almost no subjective symptoms.

Perineal lithotomy is much less frequently done than formerly, on account of the application of Bigelow's operation of litholapaxy to the great majority of calculi, and of the revival of suprapubic lithotomy and its use in a considerable proportion of the remainder. A description of the parts involved in this operation serves, however, as Treves has said, to give a proper conception of their important anatomical relationships.

The Male Perineum.—This region—a fissure when the thighs are approximated—becomes an ample lozenge-shaped space when the legs and thighs are flexed

FIG. 1625.

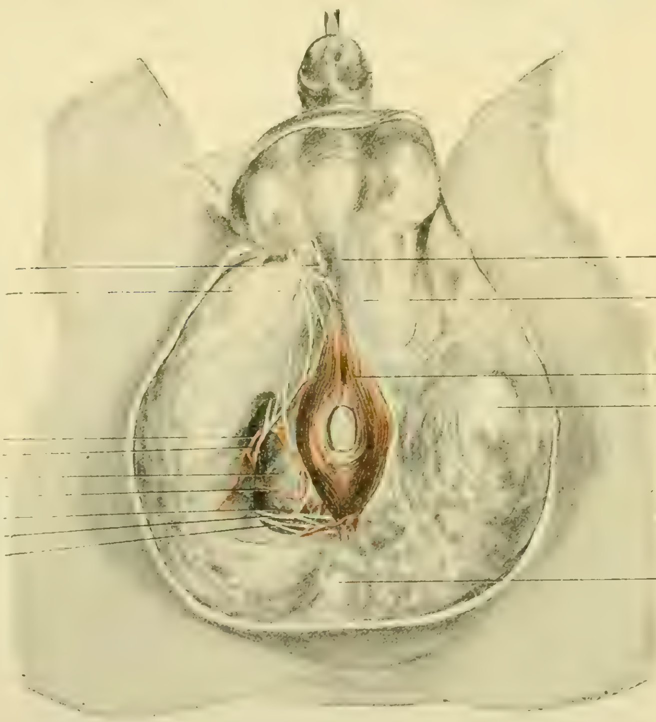
Dissection of perineum; skin has been removed, leaving superficial fascia undisturbed. Sound has been passed through urethra into bladder and scrotum drawn forward.

and the latter are strongly abducted,—the lithotomy position. It corresponds to the outlet of the pelvis. On the surface it is bounded roughly by the scrotum anteriorly, the buttocks posteriorly, and the upper limits of the inner aspects of the thighs laterally. More deeply the boundaries are the symphysis pubis and subpubic ligament anteriorly, the coccyx posteriorly, and the greater sacro-sciatic ligaments, the

ischial tuberosities and rami, and the pubic rami laterally (Fig. 1627). It is divided into two lateral symmetrical halves by a dense cutaneous ridge, the *raphe*, across which, as it represents the junction of the two fœtal halves of the perineum, no blood-vessels pass from one side to the other; and into two unsymmetrical antero-posterior triangular portions by an imaginary transverse line drawn between the anterior borders of the ischial tuberosities and running in front of the anus. The posterior of these two divisions—the portion of the outlet of the pelvis which contains the rectum and anus—is the *rectal triangle* (anal perineum). Its practical relations have been sufficiently dealt with in the article on the rectum and anus (page 1693).

The anterior division, the *uro-genital triangle* (urethral perineum), has for its deep boundaries: posteriorly the deep layer of the superficial fascia (fascia of Colles) as it passes behind the transverse perineal muscles to become continuous with the inferior layer of the triangular ligament (page 563); laterally the rami of the pubes

FIG. 1626.



Dissection of perineum, showing superficial and hemorrhoidal branches of internal pudic artery and of pudic nerves on right side; Colles's fascia exposed on left.

and ischia; anteriorly the pubic arch. Over the uro-genital triangle the superficial fascia is separable into two distinct layers, the superficial and the deep. The superficial layer contains a considerable amount of fat, and is continuous with the corresponding layer over the thighs and buttocks and with the masses of fatty tissue that fill the ischio-rectal fossæ. The deep layer, or fascia of Colles, is membranous and free from fat, and is not only applied closely to the lower edges of the transverse perineal muscles and attached to the base of the inferior layer of the triangular ligament, but is also attached to the external margin of the rami of the pubis and ischium. Anteriorly it is continuous with the deep layer of superficial fascia of the scrotum (dartos), penis, and spermatic cords, and with the fascia of Scarpa (page 515) on the front of the abdomen. When it is divided, a definite space, the *superficial perineal interspace*, is opened, which is bounded below by Colles's fascia, above by the inferior layer of the triangular ligament, laterally by the attachments of the fascia

and the ligament to the pubo-ischiatic rami, and behind by the union of the fascia with the base of the ligament.

This space or pouch contains the bulb and the crura of the penis and the muscles covering them, the superficial transverse perineal muscles, the superficial perineal nerves and vessels, and the long pudendal nerves; in its anterior part the internal pudic artery divides into its terminal branches, the dorsal artery of the penis and the artery to the corpus cavernosum. It is very important in its relations to wounds and ruptures of the urethra (*q.v.*).

In the uro-genital triangle, half-way between the centre of the anus and the perineo-scrotal junction, is the so-called "perineal centre," where the bulbo-cavernosus, the sphincter ani, and the superficial transverse perineal muscles meet, and which corresponds to the middle of the posterior edge of the fibrous shelf formed by the union of the two layers of the triangular ligament. These structures are exposed when Colles's fascia is turned back, and on either side a triangular space is

FIG. 1627.

Dissection of perineum; Colles's fascia has been cut and reflected to expose crura and bulb of penis covered by muscles; on right side ischio-rectal fossa is partly cleaned out.

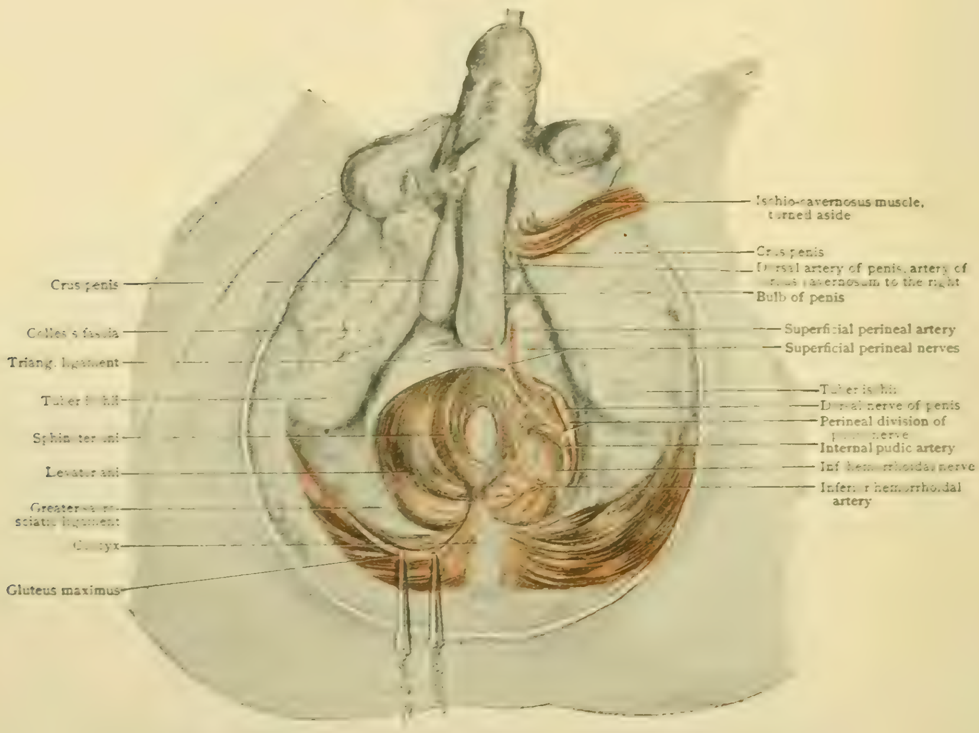
seen, the floor of which is constituted by the inferior layer of the triangular ligament. At the lateral, median, and posterior sides of the triangle lie the bulbo-cavernosus, ischio-cavernosus, and superficial transverse perineal muscles respectively (Fig. 1627).

When the inferior layer of the triangular ligament is divided, the space (*deep perineal interspace*) between that and the superior layer (as this portion of the parietal layer of the pelvic fascia is called) is opened and is found to be broader inferiorly and behind, the two layers fusing anteriorly with a dense band (*ligamentum transversum pelvis*) stretching from one pubic bone to the other, and leaving only sufficient space above it, beneath the subpubic ligament, to permit the passage of the dorsal vein of the penis. The space between the two layers (Fig. 1629) is occupied by (*a*) the compressor urethræ muscle; (*b*) the membranous urethra, about half an inch in length; (*c*) Cowper's glands (*glandulæ bulbo-urethrales*); (*d*) the beginning of the artery of the bulb; (*e*) the continuation of the internal pudic artery, which, while between the two layers of the triangular ligament and

before piercing the superficial layer, gives off the artery to the bulb. This latter artery may come off from the accessory pudic when that vessel is present (page 818), and will then be more anterior, and less exposed to division in lithotomy, than usual; or it may come off from the internal pudic before the latter has penetrated the superficial layer of the triangular ligament, and will then be behind its usual position and more likely to be wounded. When the superior or deep layer of the triangular ligament is opened, the prostate—partly covered by the median fibres of the levator ani—and the neck of the bladder are exposed (Fig. 1631), this deep layer being continuous with the prostatic sheath.

It will be seen that in reaching this point by dissection there will have been exposed certain alternating layers of fascial and muscular structures (Cunningham) as follows: (*a*) superficial fascia (superficial and deep layers); (*b*) superficial perineal muscles; (*c*) inferior or superficial layer of the triangular ligament

FIG. 1628.



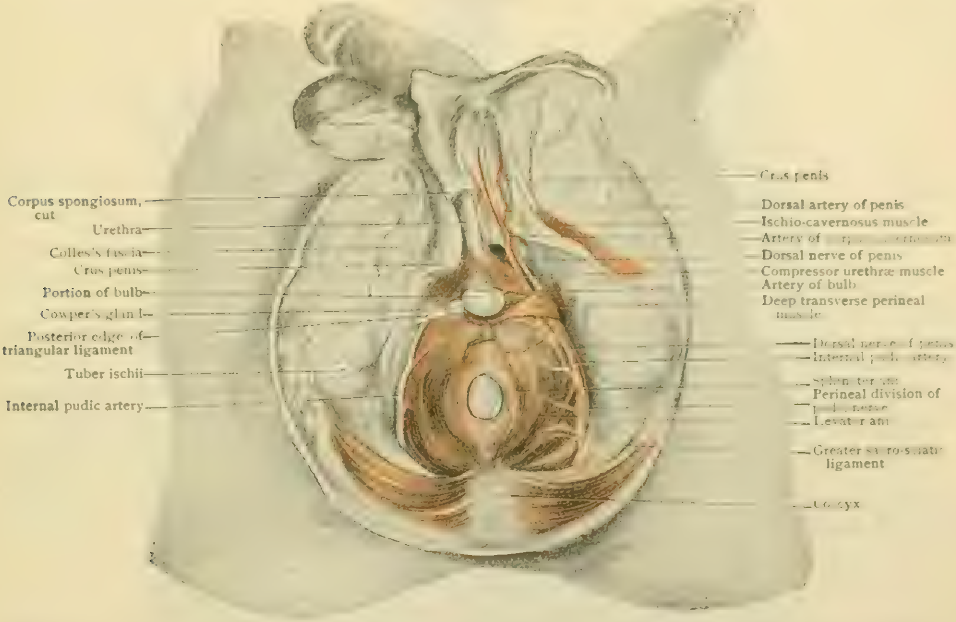
Dissection of perineum, showing inferior layer of triangular ligament and inner wall of ischio-rectal fossa partially exposed.

(fascia trigoni urogenitalis inferior); (*d*) compressor urethræ muscle; (*e*) superior or deep layer of the triangular ligament (fascia trigoni urogenitalis superior (*f*) levator ani muscle; (*g*) prostatic fascia (sheath).

Landmarks.—With the patient in the lithotomy position: (1) The pubis, coccyx, tuberosities, ischio-pubic rami, and greater sacro-sciatic ligaments may be felt. (2) The transverse diameter, between the tuberosities, is 9 cm. (3½ in.); the antero-posterior diameter, from the coccyx to the pubis, is also 9 cm. (3½ in.) on the skeleton, 10 cm. (4 in.) as measured on the living person. (3) The centre of the anus is about 4 cm. (1½ in.) from the tip of the coccyx, and is on a line drawn between the tips of the ischial tuberosities. (4) The perineal centre is approximately 4 cm. (1½ in.) in front of the anus. (5) The bulb (and its artery) are just anterior to this; its position may be indicated by a slight median surface elevation; the artery passes inward between the layers of the triangular ligament about a half

inch above the base of the latter,—*i.e.*, about one and a half inches from the anus. (6) Measured in the mid-line from the symphysis to the centre of its base, the triangular ligament extends backward about one and a half inches. (7) The membranous urethra, lying between the two layers of the triangular ligament, is a little below the middle of this line,—*i.e.*, a little less than an inch below the symphysis and from one-half to three-quarters of an inch above the anus. It measures from one-half to three-quarters of an inch in length. (8) The dorsal vein passes above the triangular ligament a little less than a half inch below the lower margin of the symphysis; the pudic artery and nerve pierce the superficial layer of the triangular ligament a little lower. (9) The distance from the surface of the perineum to the pelvic floor is about one inch near the symphysis and from two to three inches posteriorly and laterally. (10) The vesical orifice is on a horizontal antero-posterior line drawn through a point a little below the middle of the symphysis, is about an inch to an inch and a quarter behind it, and is from two and a half to three inches above the

FIG. 1629.



Dissection of perineum, in which inferior layer of triangular ligament and corpus spongiosum have been partially removed, exposing urethra covered by compressor urethræ muscle and Cowper's gland.

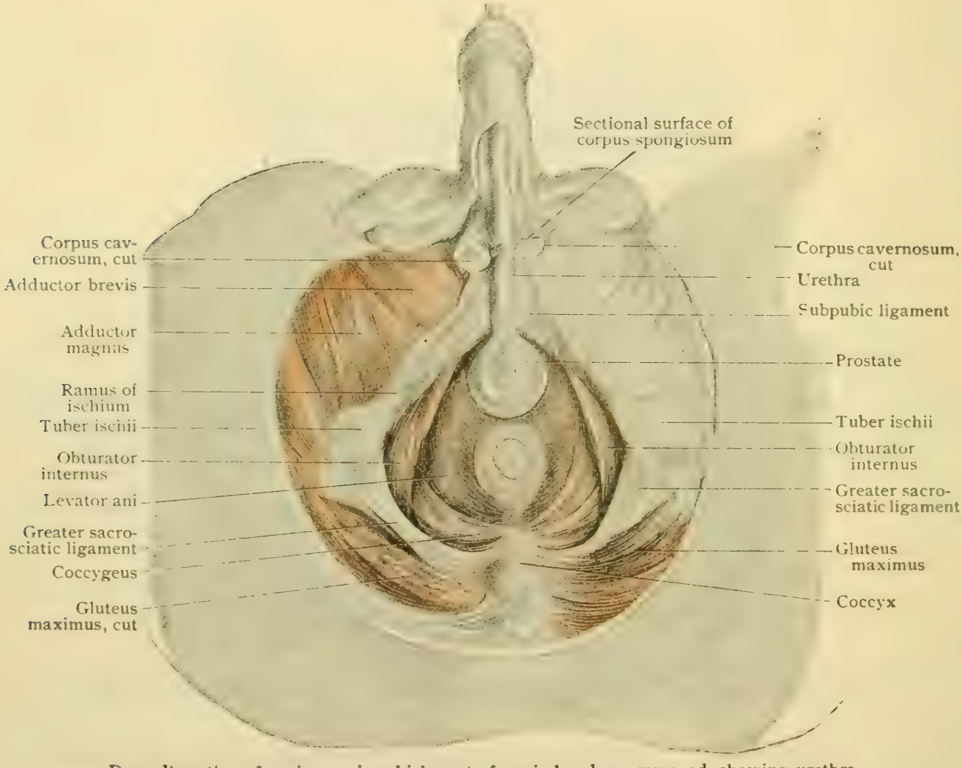
perineal surface. (11) The prostate is about three-quarters of an inch below the symphysis. (12) The pudic artery, as it lies in Alcock's canal, is about one and a half inches above the lower margin of the ischial tuberosity.

These measurements are, of course, approximate, and vary with the size of the pelvis and its outlet and the amount of subcutaneous fat, which, in the lithotomy position, may much increase the normal antero-posterior convexity of the perineal surface.

Lateral Lithotomy.—It will now be understood that in opening the bladder through one side of the perineum the incision must not extend too far forward, as it might involve the artery of the bulb, which lies a little anterior to the "perineal centre" (Fig. 1629); or too much externally, as the pudic might be wounded where it lies on the ramus of the ischium; or too far posteriorly, as, after dividing the layer of the superficial perineal fascia covering the rectal triangle, and thus opening up the ischio-rectal space, it might open the rectum itself. In the deeper parts of the wound it will be seen that if it is too extensive, or carried too far upward, it might pass completely through the left lobe of the prostate and divide the visceral layer of

the pelvic fascia (which is reflected from the gland near its upper end), favoring the development of pelvic cellulitis from urinary infiltration (page 1933); or it might divide the neck of the bladder and open up the recto-vesical fossa with the same results; or, if the prostatic incision were too extensive and too vertical, it might wound the ejaculatory ducts or seminal vesicles. The incision—which is made after a grooved staff has been introduced into the bladder, and while it is held in place by an assistant—accordingly begins at a point a little to the left of the raphe and a little posterior to the perineal centre—*i.e.*, about one to one and a quarter inches in front of the anus—and, opening the left ischio-rectal fossa, ends at the junction of the outer and middle thirds of a line drawn between the posterior margin of the anus and the ischial tuberosity. This incision should be deepest near its upper end—not far, at its upper and deepest portion, from the apex of the "perineal triangle"—and should become shallower as it passes into the ischio-rectal space. It divides skin,

FIG. 1630.



Deep dissection of perineum, in which root of penis has been removed, showing urethra emerging from prostate, which is partly exposed between levatores ani.

both layers of superficial fascia, the superficial transverse perineal muscle, artery, and nerve, the lower edge of the superficial layer of the triangular ligament, and, as it crosses the ischio-rectal fossa, the inferior hemorrhoidal vessels and nerves.

The left forefinger of the operator now guides the knife into the groove of the staff, and the incision is deepened with the knife-blade inclined laterally and pushed onward into the bladder, dividing the compressor urethræ muscle, the membranous urethra, the superior layer of the triangular ligament, a few median fibres of the levator ani, the prostatic urethra, and a portion of the left lobe of the prostate.

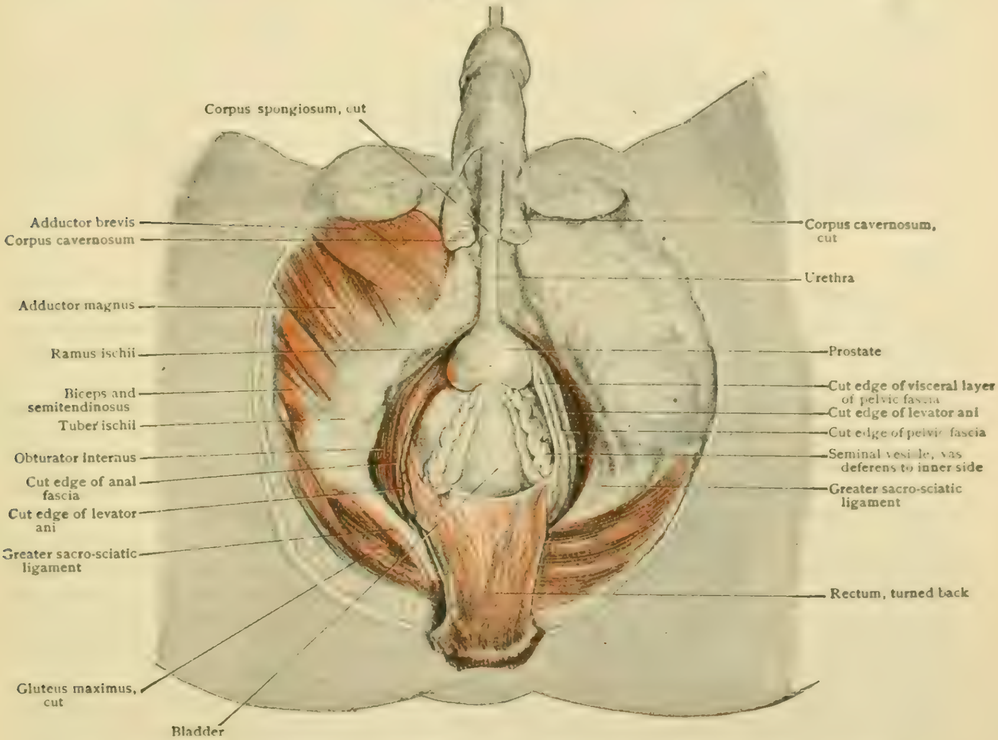
The neck of the bladder should be dilated with the finger rather than incised, and will, without serious laceration, permit the extraction of a stone of the diameter of an inch to an inch and a quarter.

In children the following facts should be borne in mind: (*a*) the relative narrowness of the pelvis, limiting the operative space; (*b*) the undeveloped condition

of the prostate, necessitating the division of more of the vesical neck and increasing the risk of opening up the pelvic fascia; (*c*) the greater mobility of the bladder (the neck of which in the adult is largely fixed by its connection with the base of the prostate), so that it has been pushed before the finger and torn from the urethra; (*d*) the situation of the bladder above rather than in the pelvis, the neck, therefore, being relatively higher than in the adult; (*e*) the looseness and delicacy of the recto-vesical fascia, permitting the easy separation of the bladder and rectum and forming a cavity which the finger may mistake for that of the bladder; (*f*) the relatively low level of the recto-vesical fold of peritoneum, exposing it to injury if the wound is unduly prolonged upward.

Median lithotomy involves the division, through the median raphe of the perineum, of the skin, superficial fascia, sphincter ani and portions of the other struc-

FIG. 1631.



Deep dissection of perineum, in which pelvic floor has been partly removed, exposing bladder, seminal vesicles, spermatic ducts, and prostate; rectum has been turned back.

tures entering into the "perineal centre," the lower portion of the superficial layer of the triangular ligament, the compressor urethræ muscle, the membranous urethra, and the apex of the prostate. The bladder is entered by dilating with the finger the prostatic urethra and vesical neck. The advantages claimed for it are: (*a*) diminished hemorrhage on account of the relatively slight vascularity of the mid-line; (*b*) lessened risk of opening the pelvic fascia; (*c*) lessened risk of wounding the ejaculatory ducts or seminal vesicles. The disadvantages are: (*a*) the narrow space between the rectum and the deep urethra, exposing the bulb and its artery to danger anteriorly and the rectum posteriorly; (*b*) the lack of space for the extraction of even moderately large calculi; (*c*) the increased risk of pushing the bladder before the finger and tearing it from the urethra. All these objections are much greater in the case of children.

Suprapubic lithotomy is done by means of an incision in the mid-line, immediately above the symphysis, dividing skin, superficial fascia, transversalis fascia

(there is no distinct linea alba at this point), and prevesical fatty connective tissue in the space of Retzius. Sometimes this fat can be gently pushed or sponged upward and carries the peritoneum with it. The method of securing a non-peritoneal area of bladder and abdominal wall for this operation (as for others involving a suprapubic cystotomy) has been sufficiently described.

The *female bladder* is less capacious than the male bladder. Its longest diameter is transverse, as posteriorly the pelvic space is occupied by the uterus and vagina, and as the female pelvis is relatively wider than that of the male.

The lesser depth of the pubic symphysis in the female and the absence of the prostate result in a relatively lower vesical outlet and a short, direct, distensible urethra, the dilatability of which (also on account of the absence of the prostate) extends to and includes the vesical neck.

As these conditions favor easy and full evacuation of the bladder, cystitis and stone are comparatively uncommon ; and as they facilitate intravesical exploration or operation per urethram, cystotomy in the female is rarely called for. Foreign bodies introduced by the urethra are relatively common in the female bladder.

The utero-vesical pouch of peritoneum does not descend so low as the recto-vesical pouch in the male. Below it the close relations between the bladder and the cervix uteri and the upper half of the vagina lead to the involvement of the bladder in many of the diseases originating in these structures. The latter relation permits of the recognition by vaginal touch of calculi impacted in the lower ends of the ureters, the orifices of which are about opposite the middle of the vagina.

THE URETHRA.

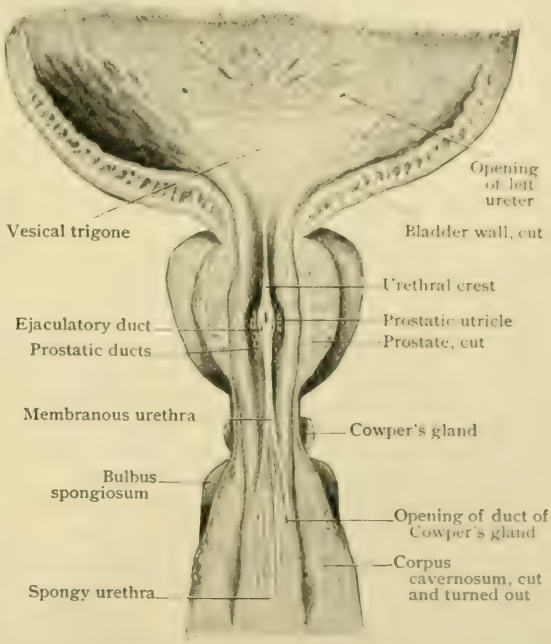
The urethra—the canal conveying the urine from the bladder to the exterior of the body—differs in the two sexes, since in the male, in addition to its primary common function of conducting the urine, it serves for the escape of the secretions of the testicles, seminal vesicles, prostate, Cowper's glands, and urethral glands. It is of interest to note that in the lowest mammals, the monotremes, in which the urethra and intestine open into a common space, the cloaca, the seminal duct is prolonged to the end of the penis as a separate canal. Embryologically the male urethra consists of two parts, a *posterior segment*—homologous with the canal in the female—beginning at the bladder and ending at the openings of the ejaculatory ducts, and an *anterior segment* including the remainder of the canal. With regard to the regions of the body in which they lie, the urethra may be considered as being composed of a *pelvic*, a *perineal*, and a *penile* portion. It is more usual, however, to describe the male urethra as consisting of the *prostatic*, *membranous*, and *spongy* portions,—a division based upon more or less definite anatomical relations of structures through which it passes.

The **prostatic portion** (pars prostatica), from 2–3 cm. (¾–1¼ in.) in length, descends with a slight curve, but almost vertically, from the *internal urethral orifice* of the urethra to the superior layer of the triangular ligament. Beyond the vesical wall, which embraces its commencement (*pars intramuralis* of Waldeyer), it is entirely surrounded by the prostate, which it pierces from base to apex (Fig. 1619). Notwithstanding, this part of the urethra admits of considerable dilatation, although ordinarily its lumen is more or less obliterated by the apposition of the anterior and posterior walls. At the two ends of this division the lumen is narrower than in the intervening part, although this spindle-form dilatation is reduced by the encroachment of a fusiform elevation, the *urethral crest* (crista urethralis) or *verumontanum*, that extends along the dorsal wall from the ridge (*uvula*) on the vesical trigone above to the membranous urethra below, into the folds of which it fades, usually by diverging ridges (frenula cristae urethralis). On transverse section (Fig. 1681), the lumen of this part of the urethra appears crescentic in outline in consequence of the projection of the crest. The most prominent and expanded part of the latter (colliculus seminalis) is occupied by the slit-like opening of the *prostatic utricle* (utriculus prostaticus) or *sinus pocularis*, a tubular diverticulum, usually from 6–8 mm. in length, but sometimes much longer, that leads upward and backward into the substance of the prostate and represents the fused lower ends of the Müllerian ducts of the embryo ; the

sinus is, therefore, regarded as the morphological equivalent of the vagina and uterus. On the lateral lips of this recess lie the small orifices of the ejaculatory ducts, while those of the prostatic tubules open into the groove-like depressions on either side of the urethral crest. The internal urethral orifice lies approximately on a horizontal plane passing through the middle of the symphysis, about 2.5 cm. (1 in.) behind the latter and an equal distance from its lower border.

The **membranous portion** (**pars membranacea**) curves downward and forward from the apex of the prostate to the bulb of the corpus spongiosum, which it enters somewhat (about 1 cm.) in advance of its posterior extremity. In its course the membranous urethra pierces both layers of the triangular ligament and is surrounded by the fibres of the compressor urethræ muscle; behind it, on either side of the mid-line, lie the glands of Cowper. This part of the canal measures only about 1 cm. in length, and is the shortest, narrowest, and least distensible of the segments. When empty, its mucous membrane is thrown into longitudinal folds, and on cross-section its lumen is stellate. In consequence of its curved course, the anterior wall is shorter than the posterior, which marks the most dependent point of the subpubic curve that lies about 18 mm. (¾ in.) below and behind the lower border and in the plane of the symphysis. Since almost the entire membranous portion lies between the layers of the triangular ligament, its mobility is much less than that of the other parts of the urethra. The short terminal part of the membranous urethra that lies below the triangular ligament and above and in front of the bulb as it enters the corpus spongiosum (**pars praetrigonalis**) is, however, not only wider and thin-walled, but much more movable,—characteristics that increase the difficulty of guiding instruments into the narrow and fixed intratrigonal segment beyond.

Fig. 1632.



Part of bladder and male urethra, exposed by opening and turning aside anterior wall, showing posterior surface of prostatic, membranous, and beginning of spongy portions of urethra.

The **spongy portion** (**pars cavernosa**) includes the remainder of the canal and terminates at the external urethral orifice. Its length varies with the size and condition of the penis, but averages about 14 cm. (5½ in.). In the flaccid condition of the penis it presents a double curve (Fig. 1619), the fixed proximal part of which continues the subpubic curve forward and slightly upward through the perineum to a point corresponding approximately with the attachment of the suspensory ligament to the dorsum of the penis, while the freely movable distal part, or *prepubic curve*, follows the pendent penis. Throughout its course this part of the urethra is surrounded by the corpus spongiosum, at first embedded near its upper border, then about in the middle, and at the termination near its lower margin covered by the thick cap of spongy substance forming the glans. The lumen of the spongy portion is variable both in size and form; at its two ends, where surrounded by the bulb and the glans, it presents fusiform dilatations, the intermediate part being of more uniform calibre. The first of these dilatations (**fossa bulbi**) occupies the bulb of the corpus spongiosum for about 2 cm., beginning about half that distance in front of its posterior extremity. Abruptly narrowing behind, towards the pars membranacea, in front the fossa gradually diminishes into the ordinary lumen of the canal. The ducts of Cow-

per's glands open by slit-like orifices on the posterior wall or floor of this part of the urethra. The terminal dilatation, the *navicular fossa* (**fossa navicularis urethrae**), occurs at the extreme distal end of the canal within the glans and opens onto the surface by a vertical slit-like aperture, the *external urethral orifice* (**orificium urethrae externum**) or *meatus*, the most contracted and least distensible part of the entire passage. Since the lateral walls of the navicular fossa are in apposition except during the passage of fluid, its lumen appears as a vertical slit on cross-section (Fig. 1674); beyond the fossa, however, the anterior and posterior walls come into contact, and hence the lumen is here represented by a transverse cleft (Fig. 1674, *C*), which in the region of the bulb is replaced by one of irregularly stellate outline.

The **female urethra**—about 3.5 cm. (1½ in.) in length—is much shorter than the canal in the male and embryologically corresponds to the portion of the latter that lies between the internal urethral orifice and the openings of the ejaculatory ducts. Except at its beginning, the canal is firmly united behind with the anterior vaginal wall, the downward and forward curve of which it closely follows until near its termination, where it turns more sharply forward (Fig. 1622). In consequence, the lower part of the urethro-vaginal septum is somewhat thicker below than above. With the exception of a slight spindle-form dilatation about the middle of its course, the lumen of the female urethra is fairly uniform, with a diameter of about 7.5 mm. during physiological distention; except during the passage of fluid, however, its walls are in contact and the mucous membrane is thrown into slight longitudinal folds. One of these on the upper half of the posterior wall, known as the *urethral crest*, is more conspicuous, ineffaceable, and continuous with the apex of the vesical trigone; it corresponds, therefore, with the similar ridge in the male urethra. The position of its termination below, on the roof of the vestibule, is marked by a low, corrugated, conical elevation or *papilla* which surrounds the external urethral orifice and lies from 1.5–2 cm. below the subpubic border. The *urethral orifice*, usually a small sagittal slit about 5 mm. in length, is subject to much variation in size and shape, being at times triangular, crescentic, cruciate, or stellate in form. On the papilla, on either side of the mid-line and close to the posterior margin of the urethral orifice, lie the minute openings of the *paraurethral ducts*, or *tubes of Skene*, from 1–2 cm. long, which are the excretory passages of small groups of tubular glands situated without the wall of the urethra. These ducts, regarded as the homologues of the prostatic ducts that open into the grooves at the sides of the urethral crest, sometimes open directly onto the posterior urethral wall just within the orificium externum.

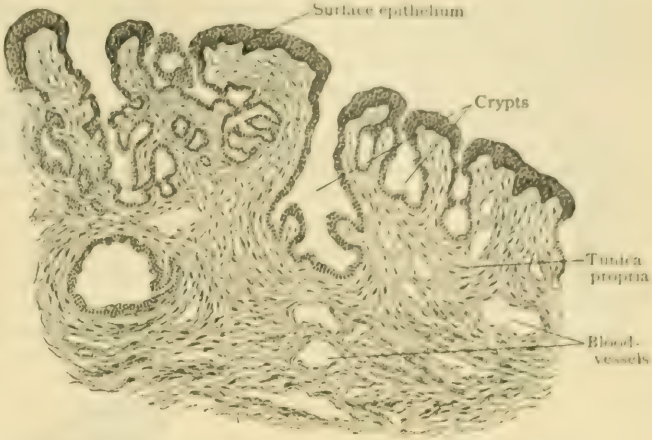
Structure.—*The Male Urethra.*—The wall of this canal consists of a mucous membrane containing a rich venous plexus and supplemented in the prostatic and membranous portions by considerable tracts of muscular tissue. The mucous membrane, which possesses an unusual amount of fine elastic fibres, is clothed with an epithelium that varies in different parts of the canal. Throughout the upper two-thirds of the prostatic portion it resembles that of the bladder, belonging to the transitional variety; on approaching the pars membranacea the epithelium becomes columnar in type, usually being simple, but in places suggesting a stratified arrangement on account of the presence of small reserve cells[1] between the outer ends of the chief epithelial elements. This variety is continued through the cavernous portion as far as the navicular fossa, where the epithelium becomes stratified squamous in type, and at the external orifice is directly continuous with the epidermis covering the glans. The deeper parts of the mucosa contain a rich venous plexus, and in places, notably in the urethral crest, assume the character of erectile tissue. The constriction of the external orifice is due to a ring of fibro-elastic tissue prolonged from the envelope and septa of the cavernous tissue of the glans.

The *muscular tissue* associated with the male urethra includes intrinsic and extrinsic fibres, the former being involuntary in character and directly incorporated with the wall of the canal and the latter being accessory bands of striped muscle derived from structures surrounding the duct. The intrinsic musculature consists of an inner longitudinal and an outer circular layer, of which the former is thinner but more widely distributed, extending from the internal urethral orifice (where it is continuous with the superficial layer of the muscle of the vesical trigone) as far forward as

[1] Herzog: Archiv f. mikro. Anat. u. Entwick., Bd. lxiii., 1904.

the orifices of the ducts of Cowper's glands. The circular fibres, outside the longitudinal, are best developed at the internal orifice, where they form a layer three or four times as thick as the longitudinal, which they accompany as a distinct, although diminishing, stratum as far forward as the termination of the membranous urethra, disappearing first on the lower and last on the upper wall of the fossa bulbi. Beyond the posterior third of the pars spongiosa the intrinsic muscle is wanting, the muscular tissue surrounding the remaining parts belonging to the erectile tissue of the corpus spongiosum (Zuckerkandl).

FIG. 1633.

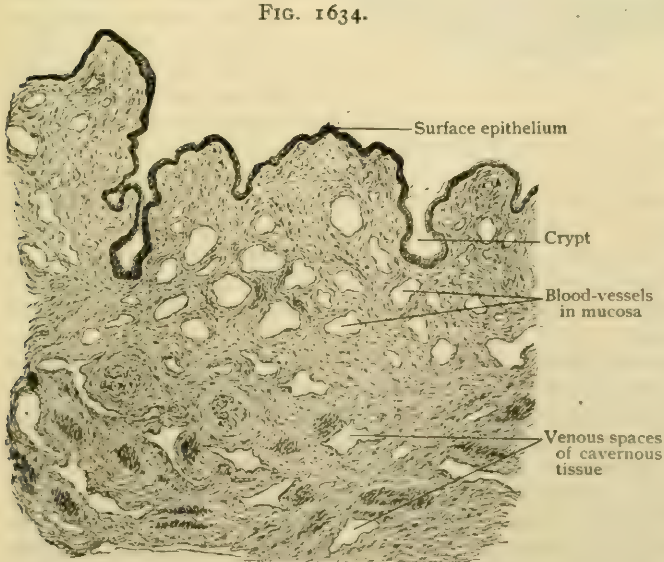


Section of mucous membrane of prostatic urethra, showing gland-like crypts in mucosa. × 45.

The *internal vesical sphincter* encircling the commencement of the urethra is derived from the deeper layer of the muscular sheet of the trigone; the muscle of the adjacent vesical wall does not directly take part in its production (Kalischer).

At the apex of the prostate the urethra is encircled by bundles of striped muscle known as the *external vesical sphincter*. Higher up these bundles lie entirely in front of the urethra in close relation with the lower border of the involuntary sphincter, in front of which they extend. Below, the external sphincter is continuous with the compressor urethræ muscle, as an upward prolongation of which it may be regarded (Holl). As it passes between the two layers of the triangular ligament, the membranous portion of the urethra is enclosed by stout annular bundles of the compressor urethræ muscle, which when stimulated to contraction, as by the presence of an instrument in the canal, may tightly embrace the urethra and embarrass the passage of the catheter. These fibres are continued forward for some distance beyond the lower layer of the triangular ligament.

FIG. 1634.



Section of wall of urethra in spongy portion, showing crypts in mucosa and numerous venous spaces. × 35.

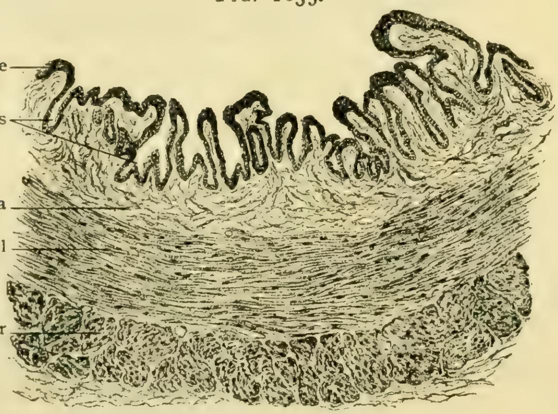
Since they affect the canal, although not in intimate relation with its wall, the fibres of the bulbo-cavernosus muscle may also be included in the extrinsic urethral musculature.

The *urethral glands*, or *glands of Littré*, embrace two groups—those within the mucous membrane and those within the submucous tissue—the ducts of which are seen with a magnifying-

glass as minute openings on the mucous membrane. The former, the *intramucous glands*, are simple in structure, consisting usually of a single alveolus, less frequently of two or three, from .070–.100 mm. in diameter. They are lined with cylindrical epithelium and occur in all parts of the urethra, being most numerous in the spongy portion (Herzog). The *submucous glands*, although small, are larger than those limited to the mucosa, but are less widely distributed, being absent in the distal half of the pars membranacea and the proximal third of the spongy portion. They are most abundant and best developed on the upper wall of the spongy portion, anterior to the openings of the ducts of Cowper's glands (Herzog). Their ducts often extend several millimetres obliquely backward, more or less parallel to the urethra, and divide into two or more slightly expanded terminal tubules which are lined with cylindrical epithelium. Where surrounded by the corpus spongiosum, the submucous glands lie embedded within the fibrous tissue of the albuginea; in the pars membranacea the glands are surrounded by the bundles of the compressor urethræ muscle.

In addition to the foregoing true, although small glands, the urethral mucous membrane is beset, along its upper wall and near the mid-line, with small *diverticula* (**lacunae urethrales**) which are little more than tubular depressions within the lining of the canal and cannot be regarded as glands, although they often receive the ducts of submucous glands that open into them. One of exceptional size (from 4–12 mm. in length) is commonly found on the roof of the navicular fossa, its orifice being guarded by a fold of mucous membrane (**valvula fossae navicularis**).

Fig. 1635.



Longitudinal section of wall of female urethra. × 50.

The Female Urethra.—As in the male, the wall of this canal consists essentially of a mucous membrane supplemented by an outer muscular tunic. The *mucous membrane*, thrown into longitudinal folds when the canal is closed, is composed of a tunica propria, rich in elastic fibres, covered with stratified squamous epithelium that above resembles the vesical type and below that of the vestibule. In the female the *urethral glands* are represented by small groups of tubular alveoli that open by minute orifices on the mucous surface and correspond to Littré's glands in the male. They are most plentiful in the upper part of the urethra, and often, especially in aged subjects, contain concretions resembling those found in the prostatic tubules (Luschka). The mucosa is also beset with small pit-like depressions, similar in character to the lacunæ in the male, into which the ducts of the glands frequently open.

The *muscular tissue* of the female urethra comprises intrinsic unstriped fibres forming part of the wall and extrinsic striated tissue outside of the canal. The former are represented by an inner layer of longitudinally disposed fibres and an outer one of circular bundles, the two being separated by an intervening stratum of areolar tissue on which a rich venous plexus confers the character of erectile tissue. At the internal orifice the circular fibres, in conjunction with those from the trigone, form the internal vesical sphincter. Between the layers of the triangular ligament the canal is surrounded by bundles of the compressor urethræ, fibres of which are prolonged into the anterior vaginal wall. The lower end of the urethra is embraced by the anterior fibres of the sphincter vaginæ muscle (Lesshaft).

Vessels.—The *arteries* supplying the urethra are from several sources, since those distributed to the canal are usually branches derived from the vessels passing to the surrounding organs. The pars prostatica receives twigs from the middle hem-

orrhoidal and the inferior vesical; the membranous portion from the inferior hemorrhoidal and the superficial perineal; and the spongy portion from the bulbar, cavernous, and dorsal arteries from the internal pudic. *In the female* the urethra is supplied by branches from the inferior vesical, the uterine, and the internal pudic for the upper, middle, and lower thirds respectively.

The *veins*, which form a rich plexus beneath the mucous membrane, in the proximal part are tributary to the vesical and prostatic veins, and in the spongy portion to the dorsal vein of the penis and the internal pudic veins. *In the female* the veins empty into the vesico-vaginal and pudendal plexus. Below they communicate with the venous spaces of the clitoris and the bulbus vestibuli (Waldeyer).

The numerous *lymphatics* within the mucous membrane form a proximal and a distal set. The former pass backward to join the lymphatics of the vesical trigone, the latter course forward and unite with those of the glans. The lymph-tracts from the spongy and membranous portions of the urethra communicate with the internal or pubic group of inguinal lymph-nodes; those from the prostatic portion are afferents to the internal iliac nodes. *In the female* the lymphatics from the upper part of the canal pass to the internal iliac nodes; below they empty into the lymph-vessels of the labia minora and communicate with the inguinal nodes.

The **nerves** are from the pudic, which conveys sensory fibres to the mucous membrane and motor fibres to the striped muscle, and from the hypogastric plexus of the sympathetic by way of the prostatic and cavernous plexuses.

PRACTICAL CONSIDERATIONS: THE MALE URETHRA.

Congenital abnormalities of the urethra are not common. *Absence* of the urethra usually causes death of the fœtus before birth, as urine is secreted and enters the bladder during intra-uterine life, the vesical distention then causing pressure upon the umbilical arteries and embarrassment of the fœtal circulation. *Atresia* of the urethra may be found at birth at any point in the canal, but if posterior to the meatus is apt to result in death of the fœtus. Occasionally it affects only the meatus, the mucous membrane of the glans presenting no orifice, but either yielding spontaneously to the child's efforts to urinate or being readily penetrated by a probe.

Contraction of the meatus so that it will admit only the finest probe is a not uncommon congenital condition, is often associated with phimosis, and may cause a sufficient degree of urinary obstruction and of reflex irritation of the susceptible nerve-centres of an infant to require meatotomy (*q.v.*).

Hypospadias.—This is a congenital deficiency in the lower wall of the urethra which may terminate at the perineo-scrotal junction or at any point anterior to it. The varieties of hypospadias are described in accordance with the degree of arrest of development (page 2040) which has occurred. If this has been extreme, the anterior orifice of the urethra may even lie in the perineum, the two halves of the scrotum remaining ununited, and often consisting of two separate pouches, which are empty when the testicles have failed to descend, and which, therefore, resemble strongly the external genitalia of the female. In these cases the penis is atrophied and is closely applied to the fissure in the scrotum. In the *peno-scrotal* variety the opening is at the junction of the anterior fold of the scrotum with the inferior surface of the penis, and the latter is apt to be somewhat better developed, although still strongly curved downward, owing to its being much shorter on its inferior than on its upper surface. In the *penile* variety of hypospadias the urethral opening may be at any point on the lower surface of the penis between the peno-scrotal junction and the corona glandis. In the so-called *balanic* hypospadias the opening of the urethra is situated on the under surface of the glans; the frenum is absent. There is often a little groove at the anterior extremity of the glans which resembles the normal meatus, but which usually ends posteriorly in a blind pouch. When the urethral orifice is situated far back, the patient is usually sterile, although not necessarily impotent if the organ is well developed. Often, however, it is so rudimentary or so markedly curved upon itself that intercourse is impossible. The forms of hypospadias involving the glans are of no physiological importance and require no treatment.

Epispadias is an absence of the upper wall of the urethra, is much rarer than hypospadias, and is often associated with exstrophy of the bladder (page 1911). It may be extensive, in which case the opening of the urethra is close to the pubes, or there may be congenital absence of the pubic symphysis.

In relation to its injuries and diseases and to its use as the route by which instruments are introduced into the bladder, the urethra may be divided into various portions, as (*a*) *anterior* and *posterior*; (*b*) *fixed* and *movable*; (*c*) *curved* and *straight*; (*d*) *narrow* and *wide*; (*e*) *dilatable* and *non-dilatable*; (*f*) *erectile* and *muscular*; (*g*) *penile*, *perineal*, and *prostatic*.

(*a*) The *anterior* urethra includes all the spongy portion and the *posterior* or deep urethra all the prostatic portion. They are separated, especially as regards infectious processes, by the intervening membranous urethra,—that portion lying between the two layers of the triangular ligament and surrounded by the compressor urethræ muscle. The contraction of that muscle, acting on the narrowed urethra of this region, constitutes a natural barrier to the backward progress of infection, and is doubtless aided in this by the resistance to tumefaction offered by the unyielding inferior layer of the triangular ligament (the arbitrary boundary of the "anterior" urethra posteriorly), and possibly, in the ordinary position of the male organ, by gravity, as the movable prepubic downward curve of the urethra (*vide infra*) begins only a little anterior to that point. The division is a practical one, and in its relation to the most common urethral infection (gonorrhœa) affects both prognosis and treatment (page 1931).

(*b*) The *fixed* portion of the urethra includes the prostatic and the membranous portions and a little—from one to one and a half inches—of the posterior part of the spongy portion. It may be said to extend from the neck of the bladder to the posterior margin of the suspensory ligament of the penis, about two and a half inches anterior to the inferior layer of the triangular ligament. Of this relatively fixed portion the membranous urethra is the only part that has practically no mobility. The prostatic portion may be moved slightly within the limits allowed by the pubo-prostatic ligaments and by the connection of its capsule with the superior layer of the triangular ligament in front and the recto-vesical fascia and rectum beneath and above. The posterior part of the spongy urethra, the "bulbous" portion, has even more motion both laterally and inferiorly, as its movement in those directions is not opposed by any strong membranous or ligamentous structure. Of course, anterior to the suspensory ligament the spongy urethra moves with the corresponding portion of the penis.

This division, like the one following, is of great practical importance in urethral or vesical instrumentation.

(*c*) The terms *curved* and *straight*, as applied to the urethra, are purely relative. With the penis flaccid and pendent there is almost no straight portion, and the urethra presents a reversed, irregular, S-shaped curve, the upper segment of which begins a little anterior to the vesical orifice and is nearly vertical, with its concavity forward in the erect position of the subject, while the lower and longer segment is less vertical, is convex anteriorly, and ends at the meatus. The whole urethra may be divided, as to its curves, into (1) a comparatively fixed *subpubic* curve, including most of the prostatic urethra, all of the membranous urethra, and that portion of the spongy urethra posterior to the suspensory ligament; and (2) a *prepubic* curve, including the remainder. The former, or fixed, curve is, for convenience, described as that part of a circle of three and one-quarter inches diameter which is subtended by a cord two and three-quarters inches long. Practically it varies greatly from this standard. It may be flattened out by downward pressure (the patient being supine) with a finger on each side of the root of the penis, thus elongating somewhat the slightly elastic suspensory ligament and depressing the anterior limb of the curve; it can temporarily be obliterated, as in passing through it a straight instrument or the straight shaft of an instrument with a terminal curve. The two ends of the curve are approximately on the level of a line drawn through the under surface of the symphysis at right angles to its vertical axis. The summit of the curve—the lowest point with the subject erect—is on a line prolonging the vertical axis of the symphysis, and is at the centre of the membranous urethra and about an inch behind and below the subpubic ligament.

The prepubic curve can be straightened by erecting or raising up the penis as is done during the use of urethral instruments, most of which, especially sounds and catheters, are made so as to correspond in their curves to the theoretical fixed curve above described. The catheters employed in certain conditions, especially prostatic hypertrophy, are elongated and given a larger curve to correspond with the elongation of the prostatic urethra and the greater curve given it by the elevation of the vesical neck (page 1981).

(*d*) As the urethra, when not distended by the passage of urine, semen, or instruments, is a mere valvular slit, the walls lying in contact, it has to be studied as to *width* or *narrowness* by various methods of dilatation during life and of injection upon the cadaver. The result of such studies demonstrates that the narrow and wider portions of the urethra alternate as follows: the external meatus (the narrowest), the fossa navicularis, the spongy urethra, the bulbous portion, the membranous urethra, the prostatic urethra, the vesical orifice.

(*e*) As to its *dilatability*,—*i.e.*, its *susceptibility to distention* by instruments,—the meatus is the least distensible, and then, in order, follow the membranous, spongy, bulbous, and prostatic portions, the latter being the most distensible.

A definite ratio (nine to four) has been thought to exist (Otis) between the circumference of the flaccid penis and that of the distended urethra. A certain proportionate relationship in size between the calibre of the urethra and the circumference of the penis does undoubtedly exist, but neither is it so definite nor is the urethral calibre so large as the above figures would indicate.

(*f*) At the point at which the prostatic urethra enters the bladder it is surrounded by the internal vesical sphincter, a muscle made up of unstriped fibres; anterior to this a double layer of unstriped muscular fibres and the glandular structure of the prostate surround the urethra. At the apex of the prostate lies the external vesical sphincter, made up chiefly of voluntary muscular fibres.

The discharge of urine from the bladder is prevented by the tonic contraction of the muscular apparatus of the membranous and prostatic urethra. As the bladder becomes distended, the internal vesical sphincter yields and the urine enters the posterior part of the prostatic urethra, causing a desire to urinate, which is resisted by the action of the voluntary fibres of the external vesical sphincter and the compressor urethræ. On passing a catheter when the bladder is full, the urethra seems about an inch shorter than it does immediately after micturition; this is owing to the participation of the posterior portion of the prostatic urethra in the retentive function of the bladder.

The compressor urethræ muscle is readily excited to reflex spasm. Ordinarily, on the passage of instruments, a moderate degree of resistance can be detected, due to the contraction of this muscle. In irritable conditions of the mucous membrane there may be excited a spasm so violent that it will be impossible to introduce a soft instrument. Such spasm may also be excited by irritation of the prostatic urethra either from distention of the bladder or from any other cause. Thus it is often found extremely difficult to evacuate the bladder when the desire to urinate has been resisted for many hours, and acute inflammation of the posterior urethra not infrequently requires the use of catheters to overcome the tight muscular contraction of the compressor urethræ which prevents micturition. Not only the introduction of sounds, but even the injection of bland liquids will cause contraction of the compressor urethræ muscle, and hence prevent such injection from reaching the membranous or the prostatic urethra. Any inflammation in these portions of the urethra will also cause the tonic contraction of the sphincter muscles to be accentuated. Hence inflammatory discharge from the membranous or the prostatic urethra will tend to flow, not forward, but into the bladder, and injections intended to reach the deep urethra will, if driven in at the meatus, extend no farther back than the inferior layer of the triangular ligament.

There seem, then, to be good grounds, both from a physiological and from a clinical stand-point, for dividing the urethra into an anterior erectile part and a posterior muscular part.

(*g*) The *penile* urethra terminates at the anterior margin of the suspensory ligament; the *perineal* urethra includes the bulbous (with the so-called pretrigonal or

prediaphragmatic portion) and membranous urethræ ; the *prostatic* urethra, of course, extends thence to the bladder. All of these terms are in constant use, and a consideration of the urethra from the stand-points suggested by its subdivisions as above described cannot fail to be useful in relation to its injuries and diseases.

Subcutaneous rupture of the urethra is rarely seen in its penile portion. In the great majority of cases (92 per cent.) it affects the perineal portion (80 per cent. from falls astride, 12 per cent. from perineal blows), and in the majority of these the bulbous urethra suffers most severely. The mechanism of rupture varies with the size and shape of the vulnerating body, but the urethra is usually crushed against either the transverse ligament or subpubic arch, the anterior face of the pubis (which is placed at an angle of only 30 degrees with the horizon), or the ischiatic or pubic rami. In cases of fracture of the pelvis or temporary or permanent disjunction of the pubic symphysis, the membranous urethra may be lacerated by the fragments or may be torn partly or completely across by the drag upon it of the triangular ligament.

The rupture may be complete or incomplete, the former being more common in the membranous urethra on account of (*a*) its fixity ; (*b*) the density of the triangular ligament ; (*c*) its proximity to the pubes and ischium ; (*d*) the relative thinness of its walls ; and (*e*) the absence of the protection afforded by erectile tissue, which is present in only a scanty layer. The symptoms are hemorrhage from the meatus or into the bladder, or both ; difficult or painful urination, or retention of urine ; swelling usually in the perineum or at the perineo-scrotal junction ; and later extravasation of urine, which will be guided in certain definite directions in accordance with the locality of the rupture (*vide infra*).

Urethritis, almost always due to gonococcus infection, but sometimes caused by the ordinary pyogenic organisms aided by congestion from trauma (catheter urethritis), may from the anatomical stand-point best be divided into *anterior* and *posterior*.

Anterior urethritis affects that portion of the urethra in front of the compressor urethræ muscle ; the following characteristic symptoms and complications are due to its situation : (*a*) free *discharge* from the meatus ; (*b*) *ardor urinæ*, due partly to the mechanical disturbance of the flow of the stream of urine (converting the urethral slit into a suitable channel and separating the apposed walls), but chiefly to the contact of the acid and saline urine with the inflamed mucosa ; (*c*) *frequent and painful erection*, due (1) to irritation of the lumbar centre, causing increased blood-supply through the dorsal arteries and the arteries to the bulb and corpora cavernosa ; (2) to the compression of the dorsal vein of the penis by clonic contraction of the compressor urethræ and bulbo-cavernosus muscles, and to the compression of the penis itself against the pubic arch by similar contraction of the ischio-cavernosus also obstructing the return current ; (3) to the loss of elasticity by the congested, infiltrated mucous membrane and submucous connective tissue, which are not able to stretch as they normally do when the cavernous bodies become engorged with blood ; (*d*) *chordee*, a curvation of the penis due to the fact that the inflammation extends to the submucous connective tissue, and thence to the trabeculæ of the erectile tissue of the spongy body. The exudation of lymph consequent upon this fills up the intertrabecular spaces, which by engorgement furnish the ordinary mechanical element of normal erection. When the organ becomes erect the corpora cavernosa are fully engorged with venous blood. The infiltrated portion of the corpus spongiosum, however, remains rigid and undilatable, the blood being unable to find its way into the partially obliterated spaces. If the inflammation extends to the corpora cavernosa, erections will be equally painful ; but in this case the curve will be upward. If only one cavernous body is involved, the curve, of course, will be towards the affected side ; (*e*) *follicular* or *peri-urethral abscess*, due to involvement of the urethral follicles and to occlusion of their mouths by swelling of the mucosa, preventing drainage into the urethra ; (*f*) *lymphangitis* and *bubo*, usually associated with retention of discharge and inflammation between the prepuce and glans, the infection extending by the superficial lymphatics and reaching one of the superficial nodes lying just below Poupart's ligament, embedded in the subcutaneous cellular tissue and above the fascia lata. The lymphatics more directly connected with the urethra itself belong to the deeper set, and run beneath the pubic arch to join the deep pelvic lymphatics and to terminate in the lumbar nodes.

A rare complication (*Cowperitis*) may result from infection of the bulbo-urethral glands through their ducts which empty into the bulbous urethra. The first symptom usually developed is pain in the perineum, much increased by pressure, and rendering sitting or walking markedly painful. The inflammatory swelling of the glands is resisted by the two layers of the triangular ligament between which they are situated and by the deep perineal fascia, and this resistance, associated with the determination of blood to the part by gravitation, imparts, as in other inflammations where the same conditions exist, a throbbing element to the pain which renders it peculiarly distressing.

Posterior Urethritis.—Although it is true that the compressor urethræ muscle constitutes a sphincter which, by its tonic contraction, keeps the membranous part of the canal constantly closed against injections forced through the meatus, the gonococcus, as it passes backward in the deeper layers of the epithelium, is not arrested by this muscle, but with few exceptions invades the posterior urethra, from which region it can readily extend to the prostatic ducts, the seminal vesicles, the vas and epididymis, and, much more exceptionally, to Cowper's glands and to the bladder.

To some or all of the above symptoms may then be added: (*a*) *frequent* and *urgent urination*, as the normal slight desire to urinate, felt when the bladder is moderately distended, the internal vesical sphincter dilates, and the urine comes in contact with the prostatic urethra, is transformed into an uncontrollable desire when the prostatic mucosa is inflamed and hypersensitive; (*b*) *tenesmus* from spasm of the internal sphincter transmitted to the detrusors and due to the same excitation in the neighborhood of the vesical neck; (*c*) *cystitis* (page 1914) may follow direct extension of the infection by way of the mucosa; (*d*) *prostatitis* (page 1980) from its spread along the prostatic ducts or into the prostatic follicles; (*e*) *epididymitis* (page 1952); or (*f*) *vesiculitis* (page 1960), from its following the vas deferens or the seminal ducts.

Chronic urethritis is apt to follow an acute attack because: (*a*) the canal affords periodical passage to a secretion, the urine, which is liable, by reason of changes in its constitution, to become an actual irritant; (*b*) it is exposed, at times of erection, to intense congestion of all its vessels, and the converse is also true, a congested or irritated spot along the urethra predisposing to erection; (*c*) gravitation, the proportionately excessive supply of blood to the region, and the absence of extravascular resistance due to the loose character of the spongy tissue, all favor the persistence of any congestion left after a first attack of urethritis; (*d*) the condition of approximation of mucous surfaces, as of the urethral walls during the intervals of micturition, is here, as elsewhere, unfavorable to the disappearance of granular or injected areas or other traces of inflammation. The tendency of the gonococcus to establish itself in the deeper layers of the mucous lining, and to multiply there where it is comparatively inaccessible, is another cause of the frequent occurrence of the chronic forms of urethral inflammation.

Stricture of the urethra is an important and frequent sequel of urethritis. It consists essentially in a contracting peri-urethral deposit of fibrous tissue due to the organization of the exudate deposited in the submucosa during the existence of a urethritis. The situation of stricture varies, but there can be no doubt that the great majority are to be found in the bulbo-membranous region, which includes a space from about one inch in front of the anterior layer of the triangular ligament to the prostato-membranous junction. The next most frequent seat is in the first two inches of the urethra. The frequency of strictures in these regions is due to the fact that they are exceptionally vascular and that chronic urethritis is especially apt to become localized at those points. The especial abundance of follicles in the bulbous urethra favors urine leakage and submucous exudate there. Gravitation in both regions favors chronic congestion and may possibly of itself explain the clinical facts as to frequency. The smallest number are found in the middle of the spongy urethra. These remarks apply to the form of stricture produced by urethritis. Traumatic stricture usually affects the membranous urethra. Stricture of the prostatic urethra is practically unknown, probably because in that region the submucous connective tissue is relatively scanty, the urethra is lined with vesical or transitional instead of

columnar epithelium and is supported on all sides by the firm glandular structure, thus offering greater resistance to and limiting the outward passage of inflammatory exudate or of urine.

The *subjective symptoms* of stricture are due to the interference of the coarctation with the normal passage of urine through the urethral canal and to the physical changes in the urethra, and the resulting irritation and inflammation.

The urethra behind a stricture becomes dilated and thinned, the walls atrophy, it is deeply congested, the increasing pressure produces pouching or dilatation, the retained urine, decomposing, sets up a superficial inflammation, the mucosa is denuded of its epithelial layer, urine escapes into the spongy tissue, and abscess or serious extravasation may follow.

During this process (which may not pass through all these stages) the most important symptoms having a definite anatomical basis are as follows :

(*a*) *Frequency of urination :* this arises first from the change in relation between the expulsive force required of the bladder and the accustomed demands upon it ; then from extension of inflammation backward by continuity until the vesical neck is involved ; often from the production of a genuine cystitis ; later from atony with retention.

(*b*) *Dribbling after urination* depends upon the retention behind the stricture of some drops of urine, which escape by gravity after the act of micturition is complete. It is not infrequently a very early symptom, dependent on irregular action of the circular muscle-fibres of the urethra. The dribbling, which is called the "incontinence of retention,"—the overflow from a distended bladder,—is a very late symptom, following retention and usually associated with a high degree of atony. The incontinence of stricture is to be diagnosticated from the incontinence of prostatic hypertrophy by the fact that it is at first worse in the daytime, and only becomes nocturnal later. The reverse is the case in prostatic incontinence. The mechanism of incontinence of urethral origin is simple. The dilatation of the urethra behind the stricture having extended to the neck of the bladder, the urinary reservoir becomes in shape a funnel, the bladder representing the base, the neck situated at the point of stricture. The patient being in the erect position, the weight of the column of urine comes directly on the stricture, which permits it to filter through drop by drop. In dorsal decubitus, on the other hand, the bladder fills up and retains its contents until the changes in it and in the urethra are very far advanced. In the prostatic patient it is possible that the physiological congestion of the lumbar cord produced by the recumbent posture makes urination more frequent at night and during the early morning hours. It lessens as the day goes on, and it is only later when the bladder becomes confirmed in irritability that diurnal frequency follows.

(*c*) *Retention of urine* may occur early and suddenly from an acute increase of the congestion of the mucous membrane of the strictured region, or it may be a late symptom and dependent on the great obstruction offered by the stricture.

Ardor urinæ, change in the character of the stream, diminution of expulsive power, vesical tenesmus, and urethral discharge may occur, but are not constant, and require no explanation from an anatomical stand-point.

(*d*) *Extravasation of urine* is one of the most serious of the late results of stricture. The localizing symptoms—those which indicate the point at which the urethra has given way—depend upon the course taken by the urine. In all that part from the meatus to the scrotal curve, extravasation is accompanied by a swelling of the penis, greatest in the immediate neighborhood of the point of escape. In the region included between the attachment of the scrotum and the posterior part of the bulb the course of extravasated urine is governed by the attachments of the deep layer of the superficial fascia, or the fascia of Colles. Extravasation of urine occurring through a solution of continuity in this region of the urethra will first follow the space enclosed by this fascia in front and below and by the inferior layer of the triangular ligament posteriorly, and as it cannot reach the ischio-rectal space on account of the attachment of the fascia to the base of the ligament, and cannot reach the thighs on account of the attachment of the fascia to the ischio-pubic line, it is directed into the scrotal tissues, and thence up between the pubic spine and symphysis until it reaches the abdomen.

When it escapes from the membranous urethra, extravasated urine is confined to the region included between the layers of the triangular ligament, and only gains access to the other parts after suppuration and sloughing have given it an outlet, the consecutive symptoms then depending upon the portion of the aponeurotic wall which first gave way. If the opening is situated behind the superior layer of the triangular ligament,—*i.e.*, in the prostatic urethra,—the urine may either follow the course of the rectum, making its appearance in the anal perineum, or, as it is separated from the pelvis only by the thin pelvic fascia, it may make its way through the latter near the pubo-prostatic ligament, and may spread rapidly through the subperitoneal connective tissue.

(*e*) The *bladder*, *ureteral*, and *kidney changes* are similar to those that follow obstruction from any other cause, and cystitis, sacculated bladder, ureteral dilatation, and pyonephritis are not uncommonly terminal conditions in cases of stricture.

Catheterism is one of the most important of the minor operations of surgery. For its proper performance, even in the normal urethra, an acquaintance with the differences in direction, mobility, dilatability, and contractility of that canal is essential (*vide supra*), as is familiarity with its relations to such structures and organs as the triangular ligament, the prostate, and the rectum (*q.v.*). The following points are worthy of mention here in their relation to the anatomy of the urethra. (*a*) The penis is gently stretched, the dorsum facing the abdominal wall to avoid folds or twists in the mobile anterior urethra. (*b*) In persons with protuberant bellies the shaft of the catheter is at first kept parallel with the line of the groin; if this is not done, the point of the instrument may be made to catch in the upper wall, at the triangular ligament, owing to the elevation of the handle necessitated by the protrusion of the abdomen; the handle should, in any event, be kept low until the tip of the instrument is about to enter the membranous urethra. (*c*) The penis is drawn up with the left hand while the instrument is gradually pushed onward, the handle being finally swept around to the median line, the shaft being kept parallel to the anterior plane of the body and nearly touching the integument. The instrument is now pressed downward towards the feet, while the left hand still steadies the penis and makes slight upward traction. After four or five inches of the shaft have disappeared within the urethra, it will be found that the downward motion of the instrument is arrested. (*d*) The fingers of the left hand are then shifted to the perineum and used as a fulcrum, while the handle is lifted from its close relation with the anterior abdominal wall and swept gently over in the median line, describing the arc of a circle. (*e*) After the shaft has reached and passed the perpendicular, the handle should be taken in the left hand and the index and middle fingers of the right hand should be placed one on either side of the root of the penis, making downward pressure (to straighten the anterior limb of the subpubic curve, *vide supra*), while the left hand, depressing the handle, carries the point of the instrument through the membranous and prostatic urethra into the bladder. The entrance into that organ will be recognized by the free motion that can be given the tip of the instrument when the handle is rotated, and by the latter remaining exactly in the median line and pointing away from the pubes when the hold upon it is relaxed.

In urethral instrumentation it should never be forgotten that the elasticity or extensibility of the urethra resides for the most part in the spongy portion, as is clearly demonstrated by erection, and this elasticity belongs in the greatest degree to the inferior wall, which permits of easy distention or elongation, and changes its dimensions and form with notable facility; while the superior wall yields with much more reluctance, and offers a certain resistance to all agents tending to depress or elongate it. This difference increases with age, and obtains especially in senile urethræ.

The extensibility of the inferior wall is brought into play even by a moderate force, and the surgeon cannot count on its resistance. It glides before an instrument, and cannot serve to guide it; it cannot be incised with any accuracy or precision; it lacerates or ruptures when surprised by distention; and it yields rapidly and easily to mechanical pressure testing its extensibility. It should be noted, too, that this elongation of the canal is chiefly at the expense of the anterior urethra. Again, the spongy portion does not yield equally in all its parts, since it has been shown that of the different regions the perineo-bulbar is the most distensible. The inferior wall of

the urethra can then be considered as normally longer than the superior surface. The term "surgical wall," proposed for the upper wall by Guyon, would seem to be merited, because it offers the shortest route to the bladder, is the most regular and constant as to form and direction, presents the smoothest and firmest surface, is the less capable of gliding before an instrument or being modified by mechanical pressure, offers the greatest resistance to rupture and penetration, is less intimately connected with important structures, and is the less vascular of the two walls. As to the calibre and distensibility of the urethra, enough has already been said ; but it should not be forgotten that there are three relatively constricted parts, the internal or vesical meatus, the external meatus, and the membranous regions ; and three dilatations, the fossa navicularis, the bulbar cul-de-sac, and the prostatic depression, the last two dilatations presenting numerous individual variations ; and in this connection it is important to remark that all three of these dilatations are excavated at the expense of the inferior wall of the canal. The urethral curve only remaining regular in the superior wall, it results that the more pronounced the curve the more accentuated are the bulbar and prostatic depressions ; and as a certain degree of lengthening of the urethra always corresponds to the greatest curve,—since these are both produced by bulbar and prostatic augmentation of volume,—one can reasonably conclude that urethræ of the greatest curves present at the same time the greatest length. With a knowledge of these facts, the instrumental exploration of the urethra becomes a matter of much accuracy and precision (Morrow).

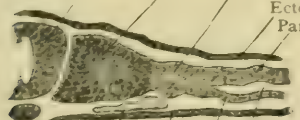
The anatomy of the various forms of urethrotomy and other operations on the urethra is sufficiently dealt with in the foregoing and in the practical considerations relative to the bladder, male perineum, and prostate (*q.v.*).

DEVELOPMENT OF THE URINARY ORGANS.

The development of the essential parts of the urinary tract—the kidney and its duct—is so intimately related with the fœtal excretory organ, the Wolffian body, that a brief account of the latter and of the principles underlying its genesis is a necessary introduction to the intelligent consideration of the subject here to be presented. The excretory apparatus of amniotic vertebrates, even in the highest mammals and man, includes three structures which, although as functionating organs existing in no single animal, stand in genealogical sequence. These are the ***pronephros***, the ***mesonephros*** or ***Wolffian body***, and the ***metanephros*** or ***definitive kidney***.

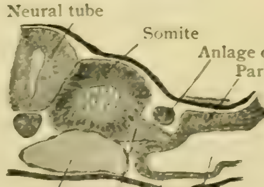
The Pronephros.—The first of these, the pronephros, sometimes called the "head-kidney" on account of its anterior position in its primary condition, in all higher forms is at best a rudimentary and functionless organ ; nevertheless, it is of extreme interest as indicating the fundamental plan upon which, in a modified form, the later Wolffian body is developed. Although, so far as known, existing as a permanent organ alone in the hag fishes (*Myxinidæ*), as a temporary structure the pronephros attains considerable development in many fishes and amphibians ; in the higher animals, even as an embryonal organ, it remains very rudimentary and transient. When adequately represented, the pronephros consists of a more or less extensive series of

FIG. 1636.



Part of transverse section of early rabbit embryo, showing primary division of mesoblast into somite, intermediate mass, and parietal and visceral layers. × 100.

FIG. 1637.



Section of slightly older embryo, showing differentiation of duct-anlage and mass in which tubules develop. × 100.

slightly transverse *tubules* within the postero-lateral body-wall that internally communicate with the body-cavity or cœlom, the openings being known as *nephrostomata*, and externally join a common canal, the *pronephric duct*, which extends caudally and empties into the dilated terminal segment of the intestinal tube, the cloaca. In relation with the inner end of each tubule, but projecting freely into the body-cavity, lies a group of convoluted blood-vessels, the ***glomerulus***, supplied by branches of the aorta. These three parts of the primitive excretory

FIG. 1638.

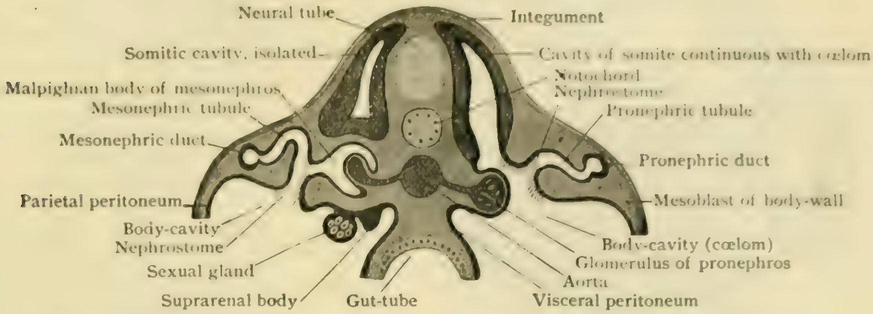
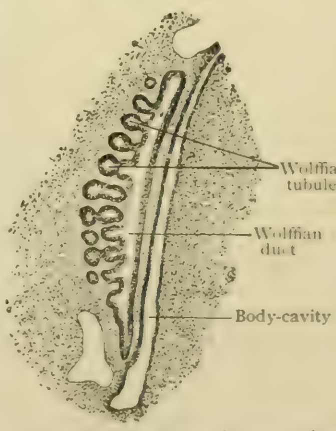


Diagram showing fundamental relations of pronephros (on right side) and of mesonephros or Wolffian body (on left side of figure). (*Wiedersheim.*)

organ provide for the essential requirements of the most elaborate urinary apparatus,—the production of the watery constituents, the excretion of the waste products, and the conveyance of the excretion so elaborated. The pronephros is fundamentally a segmental organ, the tubules being so arranged that each corresponds to a single body-segment or metamere, although by no means every such division contains a tubule. It may be assumed that the tubules of the pronephros represent the segmental ducts which in ancestral forms extended from the body-cavity directly onto the external surface of the body and thus carried off the fluids accumulated within the cœlom. In consequence of the closure of this direct communication with the exterior, which may be accepted as having occurred during the evolution of a more elaborate excretory system, the necessity for a new path of exit is met by the formation of the common pronephric duct into which the tubules open, and which, by its prolongation to and termination in the end-gut, insures the escape of the excretions.

The development of the pronephros is closely associated with the mesoblastic somites. A transverse section of an early mammalian embryo (Fig. 1636) shows the paraxial mesoblast, between the neural canal and the cleavage of the lateral mesoblast into the somatic and visceral plates, to comprise two parts, the mesial forming the *somite* and the lateral the *intermediate cell-mass.* It may be assumed that in the higher types the early somite and the intermediate cell-mass have arisen by fusion of the primarily distinct dorsal and ventral mesoblastic plates (Fig. 1638). The intermediate cell-mass soon separates into a small *duct-anlage*, situated dorsally and in close relation with the ectoblast, and a larger ventral tract comprising the remainder of the intermediate cell-mass. Within this ventral area the tubules shortly appear, and later the glomeruli. Although reaching a comparatively high development in certain fishes and amphibians (especially in Ichthyophis described by Semon), in mammals the pronephros consists of a few tubules connected with the duct, and even as an organ of embryonic life never attains more than a feeble and transient existence. In the human embryo of 3 mm. length, studied by Janosik, it was represented by two rudimentary tubules that extended from the mesothelial lining of the body-cavity towards the pronephric duct, with which one of the tubules still communicated. The pronephros of the amniotic vertebrates, therefore, must be regarded as a rudimentary inherited organ which appears in response to transmitted ancestral tendencies.

FIG. 1639.



Longitudinal section of young embryo, showing early stage of Wolffian body; tubules are joining duct. × 50.

The Mesonephros or Wolffian Body.—This organ may conveniently be regarded as comprising a later generation of excretory *tubules* opening into a common canal, the *Wolffian duct*, which is usually looked upon as the continuation and morphological persistence of the pronephric duct. In their development these tubules and duct bear a similar relation to the intermediate cell-mass as do those of the pronephros, only the body-segments involved lie farther tailward and the strict segmental arrangement of the tubules is lost owing to their multiplication and, as in mammals, precocious development. In contrast to the

rudimentary character of the pronephros, the Wolffian body not only serves for a time as the chief excretory organ of the embryo, but in many lower vertebrates continues to functionate during life. The anlage of the Wolffian duct first appears as bud-like outgrowths from the dorsal side of the intermediate cell-mass; these fuse into a strand which, separating from the cell-mass, lies as a solid cord beneath the ectoblast. The latter takes no part in the formation of the duct, which is entirely of mesoblastic origin, the appearances leading to the assumption by certain authorities of its derivation from the outer germ-layer depending upon the temporary apposition or attachment that the duct effects in consequence, probably, of its inherited inclination, since in ancestral forms the tubules opened on the free ectoblastic surface. At first solid, the Wolffian duct later possesses a lumen which gradually follows the tailward growth of the strand until, finally, it opens into the dilated end-gut or cloaca.

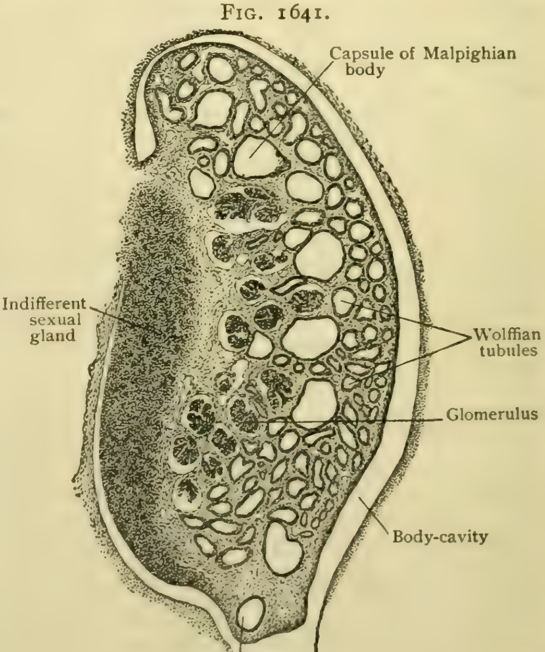
FIG. 1640.

Part of transverse section of embryo, showing commencing development of Malpighian corpuscle in Wolffian body. × 150.

In mammals the Wolffian tubules are developed within the ventral division of the intermediate cell-mass as solid cords that later acquire a lumen and an attachment to the Wolffian duct. Although in the lower vertebrates (fishes, amphibians) retaining a communication with the cœlom by means of a nephrostome, in mammals this connection is lost and the expanded inner end of each tubule comes in close relation with the convoluted vascular tuft, the glomerulus, which now, however, no longer projects freely into the body-cavity. As in the kidney, the glomerulus is supplied by an afferent twig from a branch of the aorta, and is drained by an efferent vessel that breaks up into a capillary net-work surrounding the convoluted tubule and eventually becomes tributary to the cardinal vein.

The first appearance of the Wolffian body in the human embryo occurs very early (2.4 mm. length) and at a time when the remains of the pronephros are still present. The duct precedes the tubules and opens into the cloaca in embryos of 4.2 mm. length (Keibel), the tubules, which develop independently, establishing communication with the duct shortly before. The development of the glomeruli is relatively tardy, since these bodies are not found until the human embryo has attained a length of about 7 mm. Their formation and growth continue during the first and second months until the embryo measures 22 mm. in length, when their greatest perfection is reached (Nagel).

FIG. 1641.

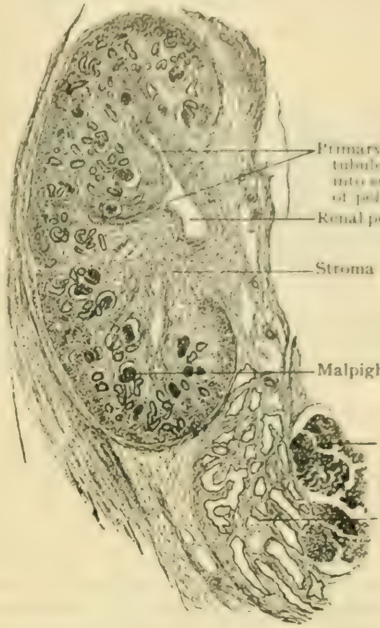


Transverse section of fully developed Wolffian body, showing also indifferent sexual gland. × 80.

When fully developed, about the end of the second month, the Wolffian body appears as an elongated organ (Fig. 1720) which extends along almost the entire length of the posterior wall of the body-cavity, on either side of the mid-line, from behind the lung-anlage to the lower end of the gut-tube. About the eighth week, the Wolffian body enters upon its stage of regression which, continuing during the third and fourth months of fœtal life, results in the gradual atrophy of the organ and its replacement as the functionating excretory gland by the kidney which meanwhile has been formed. This atrophy involves first the glomeruli of the anterior portion of the organ, which, together with many of the tubules, completely degenerate, the retrogressive process extending tailward and gradually involving the middle and posterior segments. Although the glomeruli suffer destruction, some of the tubules and the Wolffian duct for a time remain and contribute in varying degree, according to the sex

of the fœtus, to the formation of certain structures and parts of the excretory canals of the sexual glands. In the male the Wolffian duct and tubules persist chiefly as the vas deferens and the epididymis; in the female, in whom the atrophy is more complete, these remains are represented principally by the epoophoron and Gartner's duct. In both sexes certain additional rudimentary organs—the paradidymis in the male and the paroöphoron in the female—are derived from the tubules of the sexual segment of the Wolffian body. A more detailed account of these transformations is given in connection with the development of the reproductive organs (page 2037 and Fig. 1719).

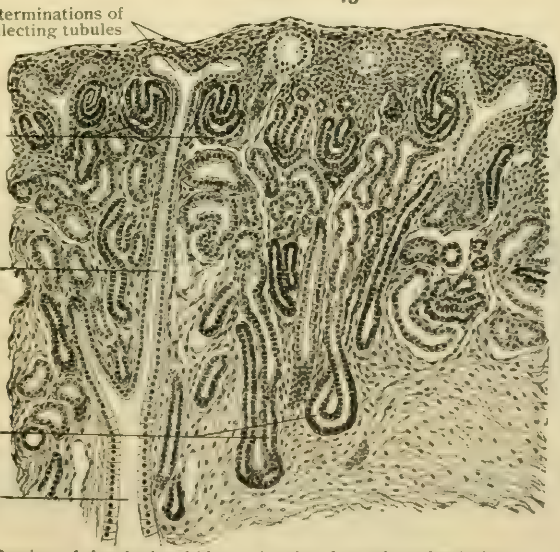
Fig. 1642.



Longitudinal section through developing kidney; portion of atrophic Wolffian body is seen below. × 35.

The Metanephros or Kidney.—The development of the definitive kidney in mammals begins as a pouch-like outgrowth from the posterior wall of the Wolffian duct, a short distance above its termination into the cloaca. In man the renal diverticulum makes its appearance during the fourth week, at which time the embryo measures from 6–7 mm. in length. At first short and wide, the stalk of the pyriform sac soon becomes tubular, growing upward and backward into the mesoblast of the posterior body-wall. This stalk rapidly elongates, and terminates above in a blind club-shaped extremity which after a time lies behind the upper atrophic segment of the Wolffian body. The tubular duct becomes the ureter and its dilated end-segment the renal pelvis. The latter is surrounded by a sharply defined oval area of compact mesoblast that is intimately concerned in the production of the convoluted kidney-tubules (of which as yet no trace is present), and hence is termed the *renal blastema*. From the ventral and dorsal walls of the primitive pelvis, which is compressed from before backward, a number of hollow sprouts grow into the surrounding mesoblastic stroma. Each is a short cylinder that terminates in a slight dilatation. At first few, these sprouts increase rapidly in number as well as in length, and by repeated dichotomous division give rise to a system of branching canals that later are represented by the straight collecting tubules of the kidney.

Fig. 1643.

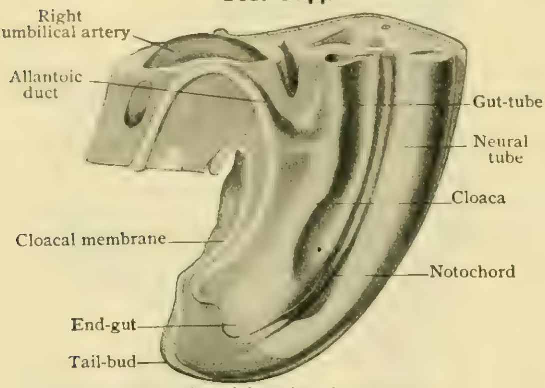


Section of developing kidney, showing formation of uriniferous tubules and collecting canals. × 100.

Concerning the origin of the remaining portions of the uriniferous tubules two opposed views obtain. According to the one, all parts of these canals develop as direct continuations of the

outgrowths from the primitive renal pelvis ; according to the other, the convoluted tubules (from their beginning in the capsule to their termination in the collecting tubules within the medullary ray) arise independently within the renal blastema, and, secondarily, unite with the duct-system from the pelvis to complete the canals. The careful studies and reconstructions of Huber[1] leave little doubt as to the correctness of the latter view, which, moreover, accords with the principle observed in the development of the pronephros and the Wolffian body, in which the tubules and the duct join subsequent to an independent formation. The attenuated proximal end of the convoluted tubule—for a short time solid and in close relation with the anlage of the glomerulus—soon becomes a sickle-like process which gradually incompletely surrounds the vascular tuft and later expands into the characteristic capsule. With the continued growth of the tubules their tortuosity becomes more marked, the loop of Henle early becoming a conspicuous feature of their course. By the third month the formation and grouping of the tubules have progressed to such extent that the surface of the young kidney exhibits the outlines of the individual lobes composing the organ. This lobulation is retained until some months after birth. In addition to the convoluted tubules, the vascular and supporting tissues are derived from the renal blastema, the condensed peripheral part of which becomes the fibrous capsule of the kidney. As the latter assumes the rôle of active excretory organ, the Wolffian body undergoes atrophy, with the exception of such parts as are concerned in the development of the sexual ducts.

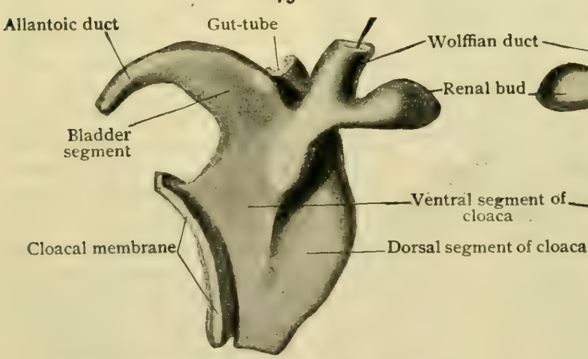
FIG. 1644.



Reconstruction of caudal portion of human embryo of seventeen days (3 mm. greatest length), showing cloaca connected with gut and allantoic duct. × 48. (*Drawn from Keibel model.*)

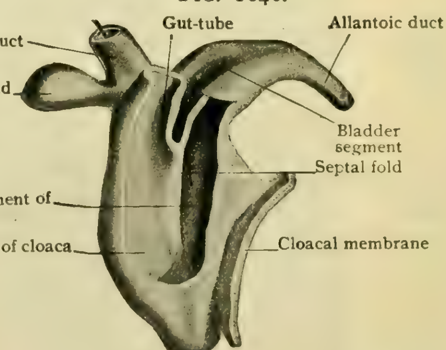
The Bladder and the Urethra.—The details of the development of the bladder and urethra in mammals and man have been materially advanced by the investigations of Keibel, Retterer, and Nagel, upon whose conclusions the following account is based. A sagittal section through the caudal pole of an early human embryo of 6.5 mm., about the beginning of the fourth week (Fig. 1645), exhibits

FIG. 1645.



Reconstruction of cloacal region of human embryo of twenty-six days (6.5 mm. length); Wolffian duct opens into ventral segment of cloaca. × 75. (*Drawn from Keibel model.*)

FIG. 1646.

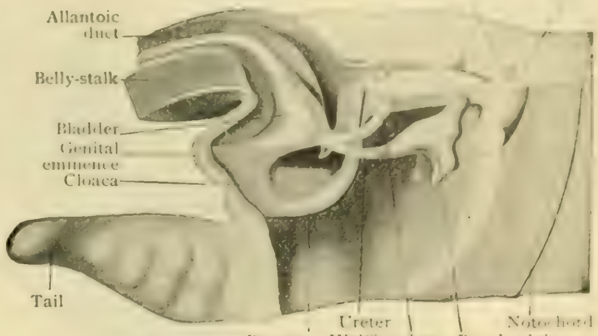


Preceding model viewed from right side, showing beginning division of cloaca into ventral (urogenital) and dorsal (intestinal) segment by longitudinal septal fold. (*Drawn from Keibel model.*)

[1] American Journal of Anatomy, vol. iv., Supplement, 1905.

the end-segment of the gut dilated into an elongated chamber, the *cloaca*, from the upper end of which the allantois passes forward and on the sides of which open the Wolffian ducts. The ventral wall of this space is thin, and consists of the opposed outer and inner germ-layers alone, no mesoblast intervening. This ecto-entoblastic septum is the *cloacal membrane*. During the fourth week the subdivision of the cloaca into a ventral and a dorsal compartment begins by the formation of a frontal fold that projects downward from the angle between the gut and the allantois. Subsequently this partition is supplemented by two lateral folds that appear on the side walls of the cloaca and are continuous above with the frontal fold (Fig. 1646). By the union of these three plicæ, above and from the sides, a septum is formed that gradually grows caudally and subdivides the cloaca into a ventral allantoic and a dorsal intestinal chamber. This partition, however, for a time is incomplete below, communication between the two spaces being thus maintained.

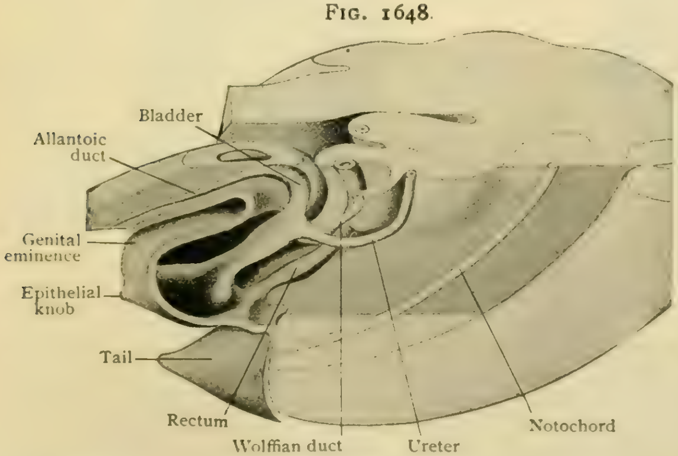
Fig. 1647.



Reconstruction of cloacal region of human embryo of thirty-three days (11.5 mm. length); cloaca now incompletely separated into uro-genital and intestinal segments. × 25. (*Drawn from Keibel model.*)

During these changes the short canals common to the Wolffian ducts and the primitive ureters are drawn into the ventral chamber, the four tubes thereafter opening independently, but in close proximity, on the posterior wall of the ventral cloaco-allantoic space. This undergoes further differentiation into an upper (vesical) and a lower (genital) segment, the latter gradually narrowing into a tubular space, closed below by the fore part of the cloacal membrane, which becomes the *uro-genital sinus* and, after rupture of the membranous floor, communicates with the exterior. For a time the orifices of the Wolffian ducts and the ureters are closely grouped, those of the former, however, lying nearer the mid-line and slightly higher than the more widely separated ureteral openings.

Fig. 1648.

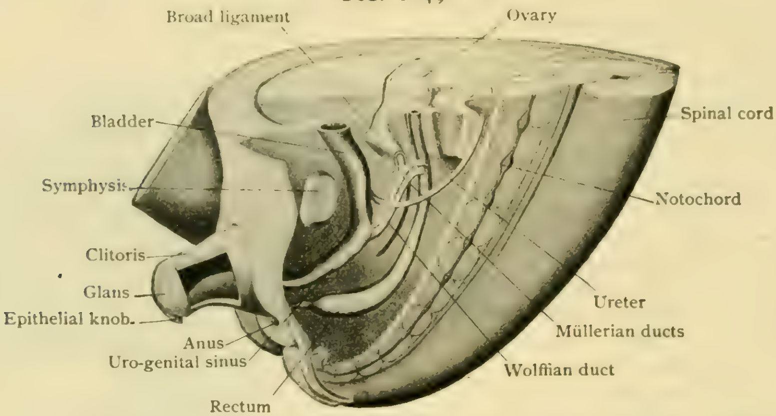


Reconstruction of cloacal region of human embryo of thirty-seven days (14 mm. length); ureter now opens independently into uro-genital sinus, which above contributes lower segment of bladder and below is now almost separated from gut-tube. × 17. (*Drawn from Keibel model.*)

During the second month an important modification of these relations occurs, associated with elongation and expansion of the upper part of the vesical segment, by which the ureters are drawn upward and the Wolffian ducts downward. The intervening tract corresponds to the lower segment of a spindle-shaped sac that extends upward and is continued towards the umbilicus by the allantois. The upper part of this sac, which is the dilated allantois, forms the body and summit of the bladder and the urachus; the lower part, into which the ureters open (Fig. 1649) and which is derived from both allantois and cloaca, differentiates into the vesical trigone and the urethra as far as the openings of

the ejaculatory ducts,—the permanent representatives of the Wolffian ducts. In the female the tract produces the entire urethra, since the orifice of the sexual canals opens into the uro-genital sinus. The bladder, therefore, is composite in origin, its

FIG. 1649



Reconstruction of human embryo of nine weeks (25 mm. length); ureter has migrated to bladder, leaving Wolffian and Müllerian ducts attached to uro-genital sinus, which is completely separated from intestine. × 10. (*Drawn from Keibel model.*)

upper part being from the allantois alone, while in the formation of the trigonal region both allantois and cloaca take part. The remaining portions of the urethra in the male are formed by the extension of the uro-genital sinus along the under surface of the corpora cavernosa of the developing penis (page 2044).

THE MALE REPRODUCTIVE ORGANS.

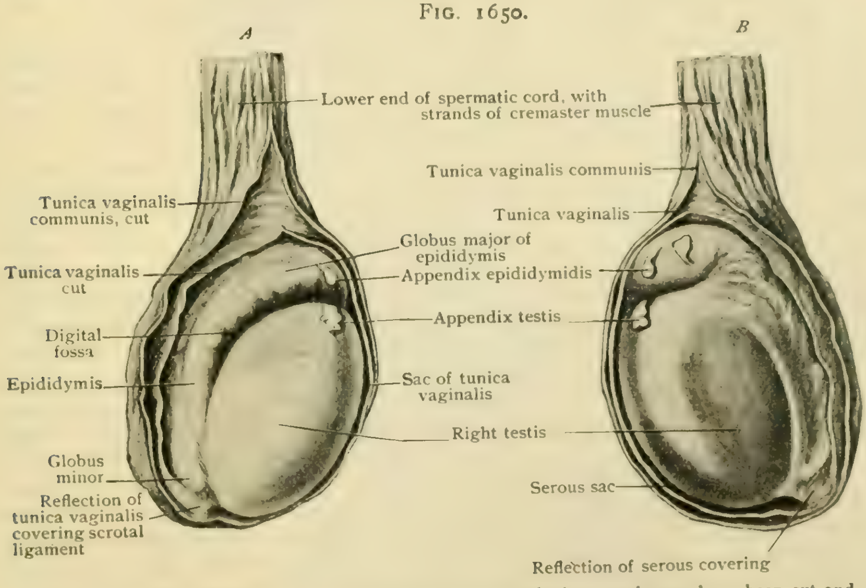
THIS group comprises the sexual glands (the *testes*), the ducts (*vasa deferentia*) and their appendages (the *seminal vesicles*), the copulative organ (the *penis*), and certain accessory glands (the *prostate* and *Cowper's glands*). Although at first situated within the abdominal cavity, the testes migrate through the inguinal canals into the scrotum, which sac they usually gain shortly before birth. In their descent they are accompanied by blood-vessels, lymphatics, nerves and their ducts, which structures, with the supporting and investing tissue, constitute the spermatic cords that extend from the internal abdominal rings through the abdominal wall to the scrotum.

THE TESTES.

As often employed, the term "testicle" includes two essentially different parts, the testis—the true sexual gland—and the epididymis, the highly convoluted beginning of the spermatic duct.

The testes, or testicles proper, the glands producing the seminal elements, are two slightly compressed ellipsoidal bodies so suspended within the scrotum—the left lower

FIG. 1650.



A, antero-lateral view of right testicle after enveloping membranes have been cut and turned aside; *B*, antero-median view of same.

than the right—that their long axes are not vertical, but directed somewhat forward and outward. Each testis measures from 4–4.5 cm. ($1\frac{1}{2}$–$1\frac{3}{4}$ in.) in length, about 2.5 cm. in breadth, and 2 cm. in thickness, and presents a lateral and a medial surface, separated by an anterior and a posterior border, and an upper and a lower pole. The lateral surface looks outward and backward, and the flatter medial one inward and forward. Both surfaces, as well as the anterior border, are completely covered with serous membrane (the visceral layer of the tunica vaginalis) and are, therefore, smooth. The rounded anterior border is free and most convex, the much less arched posterior border, covered by the epididymis and attached to the spermatic cord, being devoid of serous membrane and corresponding to the hilum. In consequence of the obliquity of the long axis of the organ, the upper pole, capped by the head of the epididymis, lies farther outward and forward than the more pointed lower one, which is related to the tail of the epididymis and attached to the scrotal ligament (page

2042). The testis is of a whitish color, and, although readily yielding, imparts a characteristic impression of resilience when compressed between the fingers.

Architecture of the Testis.—The framework of the testicle proper consists of a stout capsule, the *tunica albuginea*, a dense fibro-elastic envelope from .4–.6 mm. in thickness, that gives form to the organ and protects the subjacent soft glandular tissue. Along the posterior border of the testis the capsule is greatly thickened and projects forward as the *mediastinum testis* or *corpus Highmori*, a wedge-shaped body (from 2.5–3 cm. in length), from which radiate a number of membranous septa that pass to the inner surface of the tunica albuginea. In this manner the space within the capsule is subdivided into pyramidal compartments, the bases of which lie at the periphery and the apices at the mediastinum. These spaces contain from 150 to 200 pyriform masses of glandular tissue, more or less completely separated from one another, that correspond to *lobules* (**lobuli testis**). Each of the latter is made up of from one to three greatly convoluted seminiferous tubules, held together by delicate vascular intertubular connective tissue.

The *seminiferous tubules*—from .15–.25 mm. in diameter and from 25–70 cm. (10–28 in.) in length—begin as blind canals, which are moderately branched and very tortuous (*tubuli contorti*) throughout their course until they converge at the apex of the lobule, where they pass over, either directly or after junction with another canal, into the narrow, straight tubules (*tubuli recti*) that enter the mediastinum and unite into a close net-work, the *rete testis*. The latter extends almost the entire length of the mediastinum, and consists of a system of irregular intercommunicating channels, the cuboid epithelial lining of which rests directly upon the ensheathing fibrous tissue of the mediastinum. With these passages the canals of the testicle proper end, the immediate continuation of the spermatic tract being formed by from fifteen to twenty tubules, the *ductuli efferentes*, that pierce the tunica albuginea along the posterior border and near the upper pole of the testis and, forming the *coni vasculosi*, connect the sexual gland with the tube of the epididymis.

FIG. 1651.

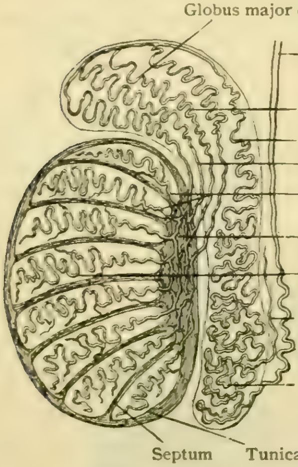


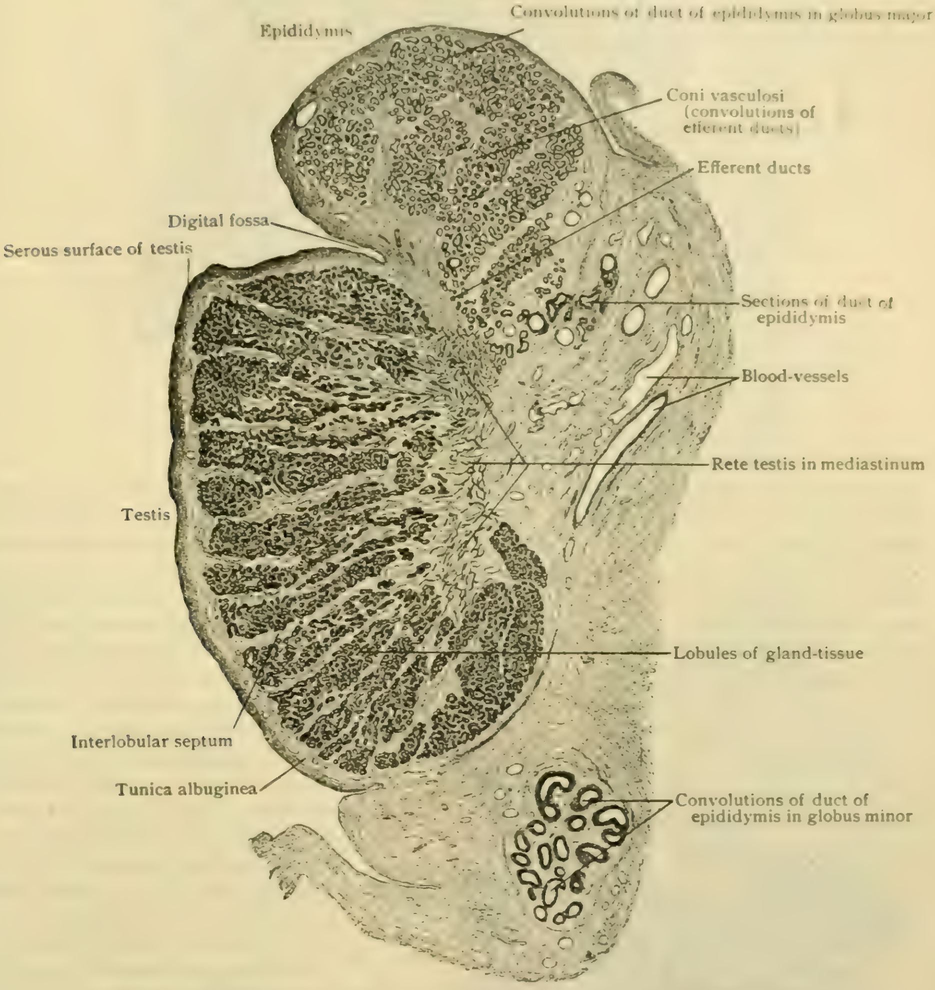
Diagram showing relations of secretory tubules and system of ducts.

Structure.—In contrast to the dense fibro-elastic tissue that composes the *framework* of the testis,—the capsule, mediastinum, and interlobular septa,—the connective tissue occupying the spaces between the seminiferous tubules is loose in texture and arrangement, consisting of delicate bundles of white fibrous tissue in which elastic fibres are few or absent. In addition to the plate-like cells, leucocytes, and eosinophiles that occur in varying numbers within the meshes of this tissue in conjunction with blood-vessels and nerves, groups or cord-like masses of peculiar polygonal elements, the *interstitial cells*, also occupy the intertubular stroma, especially in the vicinity of the mediastinum. These cells (Fig. 1654), from .015–.020 mm. in diameter, possess relatively small round or oval eccentrically placed nuclei and a finely granular protoplasm that usually contains numerous brownish droplets, pigment particles, and, sometimes, crystalloid bodies in the form of minute needles or rods. In some animals, notably in the hog, the deeply colored interstitial cells form conspicuous tracts that impart a dark tint to the testicle in section. Their significance is uncertain, but there is reason to regard these cells as concerned in internal secretion, producing a specific substance.

The wall of the convoluted **seminiferous tubules** consists of a delicate tunica propria, composed of an inner elastic lamella strengthened externally by circularly disposed fibres, within which are several layers of *epithelial cells*. The latter vary not only before and after the attainment of sexual maturity, but subsequently with functional activity or rest; in man, however, the variations depending upon these

causes are much less marked than in animals, in which sexual activity is limited to definite periods. Seen in sections of the mature human testicle (Fig. 1654), the epithelium lining the seminiferous tubules includes two chief kinds of cells, the *supporting* and the *spermatogenetic*. The former—the *cells of Sertoli*—take no active part in the production of the spermatozoa, but serve chiefly as temporary supports for the more essential elements during certain stages of spermatogenesis. They are elongated elements of irregularly pyramidal form that rest by expanded bases upon the membrana propria, and project towards the lumen of the tubule between the layers of the

FIG. 1652.



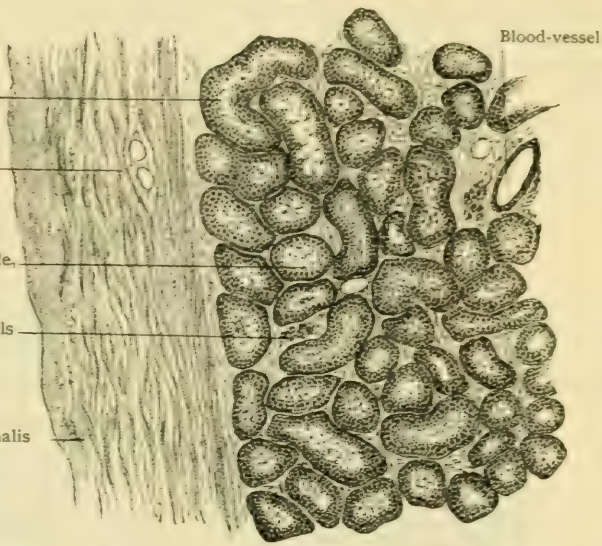
Sagittal section of testicle of child, showing general arrangement of framework and gland-tissue and of canals connecting epididymis with testis. × 10.

surrounding spermatogenetic cells. The large oval nuclei of the Sertoli cells are conspicuously meagre in chromatin, and lie towards the middle of the cell at some distance from its base. The outer part of the protoplasm contains fat-droplets, the inner zone being granular or often longitudinally striated. Where the tubuli contorti pass into the straight tubules the supporting cells become reduced in height and form a layer of simple columnar cells continuous with the low cuboidal epithelium lining the rete testis.

The *spermatogenetic cells* include three forms that stand in the relation of succeeding generations to one another, those representing the oldest lying nearest the

membrana propria, and the youngest, from which the spermatic filaments are directly derived, next the lumen of the tubule. The first generation, the *spermatogones*, lie at the periphery between the cells of Sertoli, and, although small round elements,

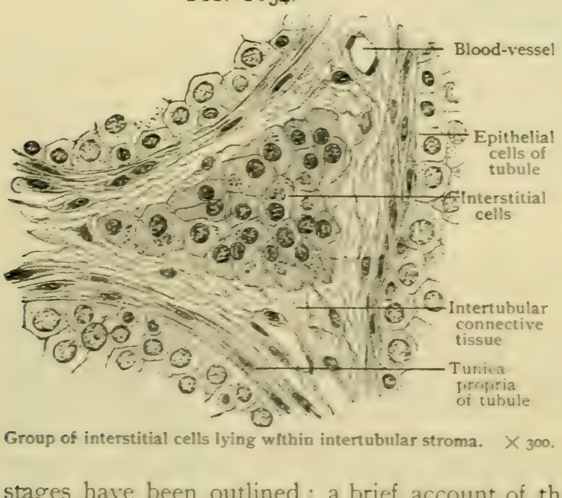
FIG. 1653.



Portion of cross-section of testis, showing dense fibrous envelope and adjacent seminiferous tubules. × 30.

possess nuclei exceedingly rich in chromatin. The division of these cells results in two cells, of which one retains the position of the parent cell, which it replaces as a new spermatogone destined for a succeeding division, while the other passes inward, enlarges, and becomes a mother cell or *primary spermatocyte* of the second generation. This element, conspicuous by reason of its size and large nucleus, undergoes mitotic division and gives rise to daughter cells or *secondary spermatocytes*. The latter almost immediately divide and produce smaller cells, the *spermatids*, by the transformation of which the spermatic filaments are directly produced. It is important to note that the spermatids contain only one-half of the number of chromosomes normal for the ordinary (somatic) cells, a like reduction (page 18) occurring in the matured ovum.

FIG. 1654.



Group of interstitial cells lying within intertubular stroma. × 300.

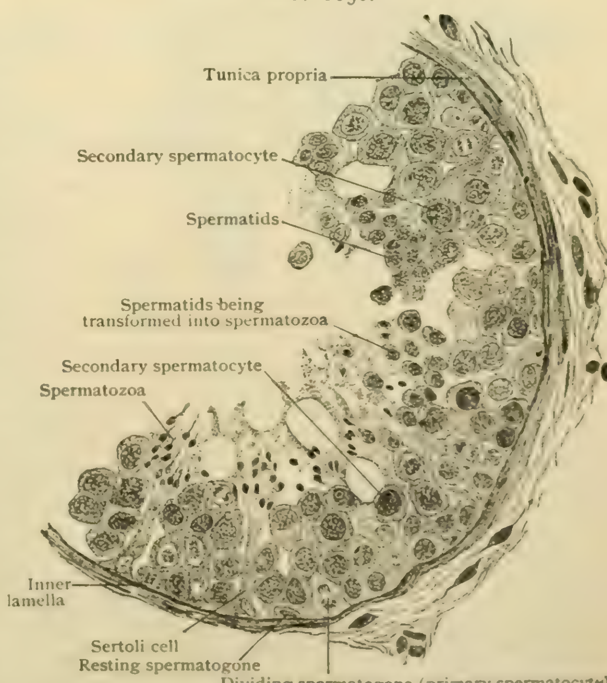
Spermatogenesis. — The cytological cycle resulting in the production of the spermatozoa from the epithelial cells lining the seminiferous tubules comprises four principal stages: (1) division of the spermatogones into spermatocytes; (2) division of the latter into spermatids; (3) transformation of spermatids into spermatozoa; (4) completed differentiation and liberation of spermatozoa. The changes incident to the first and second of these stages have been outlined; a brief account of the subsequent changes may here be added. The spermatids, at first small cells with round nuclei, elongate, their nuclei coincidently becoming oval and smaller, but rich in chromatin, and shifting to the

end of the cell most removed from the lumen. The modified spermatids now become closely related with a Sertoli cell, with the protoplasm of which they fuse. The structure thus formed, known as the *spermatoblast*, consists of an irregular nucleated conical protoplasmic mass (Fig. 1657, 27), with the inner end of which the radiating clusters of partially fused spermatids are blended. The succeeding changes include the transformation of the elongated nucleus of the spermatid into the head and of its centrosome into the neck-granules of the spermatozoon, while from the protoplasm of the spermatid, possibly in conjunction with that of the spermatoblast, the flagellate tail-filament is derived. As the spermatozoa become more and more differentiated, they appear as fan-shaped groups in which the heads are always buried within the spermatoblast and the tails directed towards the lumen of the canal. After separation, which subsequently takes place, the liberated spermatozoa occupy the centre of the tubule as masses which often occlude its lumen and in which the seminal filaments are disposed in peculiar whorl-like groups. Their complete development, however, is deferred until they reach the tube of the epididymis, during the passage through which highly tortuous path they attain maturity and lose the protoplasmic remains of the spermatids that usually for a time adhere to the middle-piece. The spermatogenetic process does not involve uniformly all parts of the seminiferous tubule, but is manifested with wave-like periodicity; consequently sections taken through the same tubule a few millimetres apart exhibit different stages of the cycle, although the cells are never all of one phase.

FIG. 1655.

Part of mediastinum, showing irregular channels of rete testis. × 75.

FIG. 1656.



Portion of seminiferous tubule, cut transversely, showing lining cells in various stages of spermatogenesis. × 350.

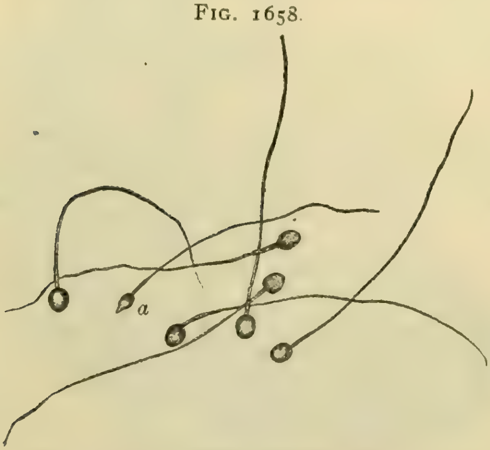
The **spermatic filaments** or **spermatozoa**, the essential male reproductive elements, are, like the ova, direct derivations of epithelial cells that are descendants

Fig. 1657.

Diagram illustrating phases of one complete cycle of spermatogenesis. Sequence of figures shows in detail growth (1–6) and division (7–8) of spermatogone; growth and division of primary spermatocyte (9–19) into secondary spermatocytes; division of latter (20–21) into spermatids (22–24); fusion of these with Sertoli cell to form spermatoblast (25–26); differentiation (27–31) and final liberation (32) of spermatozoa. (*After Ebner.*)

of the primary indifferent sexual elements. Unlike the ova, however, which are relatively large and often absolutely huge, and, apart from size and minor distinctions, fairly similar in all vertebrates, the spermatic filaments present great diversity in form and detail and represent a high degree of specialization. The human spermatic filament is small, and consists of an ovoid *head*, a cylindrical *middle-piece* of uncertain extent, and a greatly attenuated and prolonged *tail*,—the propelling organ of the flagellated cell. The mature element measures about .050 mm. in its entire length, of which only about .005 mm. is contributed by the head, probably about the same by the middle-piece, and from .040–.045 mm. by the tail. The *head*, somewhat flattened in front and hence pyriform in profile, although rich in chromatin, appears homogeneous, since the chromatin is uniformly distributed and not arranged as threads or mesh-works. The structural basis of the remaining parts of the spermatic element is a delicate *axial fibre* that extends from the head to the tip of the tail (Fig. 12) and is in-

Fig. 1658.



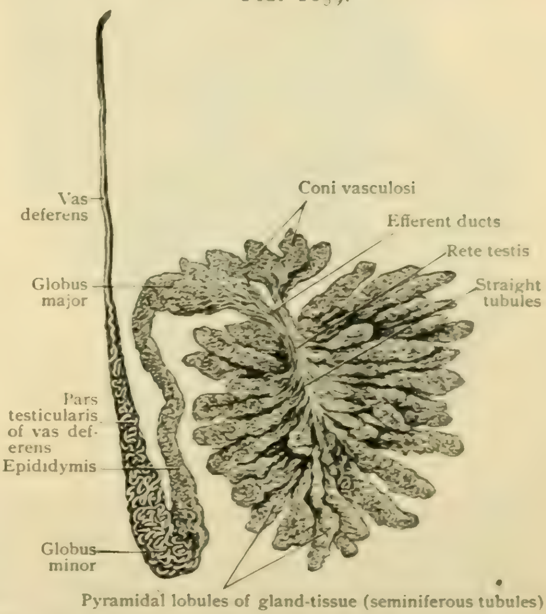
Human spermatic filaments seen from the broad surface, except *a*, which is in profile. × 800.

vested by a delicate envelope, with the exception of the last .004–.006 mm. that continues uncovered as the attenuated *end-piece*. In front, minute spherical thickenings, the *neck-granules*, mark the termination of the axial fibre, where it joins, but does not penetrate, the head. They probably represent the centrosome of the spermatid. Within the middle-piece the envelope surrounding the axial fibre, after the action of certain stains, exhibits markings that suggest the presence of a spirally arranged filament of great delicacy.

THE EPIDIDYMIS.

The epididymis, the greatly convoluted beginning of the seminal duct, is a crescentic body, triangular in section, that covers the entire posterior border and the adjacent part of the outer surface of the testis. Its enlarged upper end or *globus major* (**caput epididymidis**) covers the superior pole of the sexual gland and is attached to the latter not only by connective tissue and serous membrane (as is the globus minor), but by the efferent ducts that establish communication between the testis and its excretory canal. The succeeding part, the *body*, gradually tapers as it descends to the lower pole, at which point the epididymis presents a second and less conspicuous enlargement, the *globus minor* (**cauda epididymidis**), that bends backward to become the vas deferens. The latter passes upward along the median side of the posterior border of the epididymis to ascend in the spermatic cord. Where attached to surrounding structures, as at its two ends where in contact with the testicle and along its posterior border where blended with the spermatic cord, the epididymis is devoid of serous covering; in other places it is completely invested by the tunica vaginalis, a deep recess, the *digital fossa* (**sinus epididymidis**) intervening between the body of the epididymis and the adjacent surface of the testis. The bulk of the globus major depends upon the aggregation of from twelve to fifteen conical masses (**lobuli epididymidis**) formed by the *efferent ducts* and their tortuosities, the *coni vasculosi*, that pass from the upper end of the testis and connect the rete testis with the *canal of the epididymis*.

FIG. 1659.



Dissection of testicle after tubules have been filled with quicksilver; testis has been separated into the component lobules.

The latter (**ductus epididymidis**), beginning in the globus major, receives the efferent ducts and becomes greatly convoluted, the extraordinary windings of the single tube contributing the chief bulk of the body and the tail of the epididymis. When unravelled, the canal measures from 5–5.5 m. (18–20 ft.) in length, its remarkable convolutions sufficing to pack away this long duct within the small volume of the epididymis.

Structure.—The conical lobules of the globus major are enclosed by a fibrous envelope resembling but less robust than the tunica albuginea testis, within which the convolutions of a single tubule are held together by delicate vascular connective tissue. The transition of the channels of the rete testis into the *efferent ducts* is marked by an abrupt change in the character of the lining epithelium, the low cuboidal cells of the former giving place to irregularly ciliated columnar elements within the latter. The tubules—from .2–.5 mm. in diameter—present an irregular lumen, owing to the inconstant thickness and pitted surface of their epithelium. Just before terminating

in the canal of the epididymis, the tubules become narrowed and surrounded by a thin layer of circularly disposed involuntary muscle. The *canal of the epididymis*—from .4–.5 mm. in diameter—is lined throughout by a double layer of tall and slender columnar cells, the free ends of which bear groups of cilia of exceptional length that adhere and form pointed tufts surmounting the cells. A noteworthy feature of the wall of the canal is the layer of involuntary muscle, from .015–.030 mm. in thickness, that encircles the membrana propria and, especially in the globus minor, almost entirely replaces the stroma of the mucous membrane. Externally the muscle fades into the connective tissue holding together the convolutions of the canal.

Fig. 1660.

Section across lower part of epididymis. × 15.

Vessels of the Testis and Epididymis.—The *arteries* supplying these organs are the spermatic and the deferential, the former being distributed especially to the testis and the latter to the epididymis. An additional source is provided by anastomoses with the cremasteric artery. The spermatic artery (**a. testicularis**)—a slender branch from the abdominal aorta arising a short distance below the renal—is distinguished by its long course necessitated by the migration of the sexual gland from the lumbar region into the scrotum. On reaching the posterior surface of the testicle, it divides into three or four branches that enter the mediastinum and break up into superficial and deep twigs, which follow the tunica albuginea and the septa respectively and form the rich capillary net-works surrounding the seminiferous tubules. One or more branches pass to the head of the epididymis and anastomose with the artery of the vas. The latter (**a. deferentialis**), from the inferior or superior vesical, accompanies the spermatic duct and supplies chiefly the body and tail of the epididymis, by its connections with the spermatic artery establishing an anastomosis that may become of importance in maintaining the nutrition of the testicle.

The *veins*, superficial and deep, emerge from the testis and, joining with those from the globus major, form several stems of considerable size that ascend within the spermatic cord in front of the vas deferens, while those from the body and tail of the epididymis unite into a smaller posterior group that accompany the canal (page 1960).

The *lymphatics* of the testicle, beginning in the walls of the tubules and the surrounding connective tissue, follow in general the course of the veins as a superficial and a deep set, and emerge as a half-dozen or more relatively large trunks to which the lymphatics of the epididymis are tributary. Within the spermatic cord they accompany the groups of veins, and finally empty into the lumbar lymph-nodes.

The **nerves** of the testis and epididymis, chiefly sympathetic fibres destined for the walls of the blood-vessels, accompany the latter as the *spermatic* and the *deferential plexuses* that surround the corresponding arteries. Medullated fibres, probably conveying sensory impressions, occur among the more usual pale ones. The relations between the terminations of the nerves and the tubules are uncertain, Letzerich and Sclavunos describing intercellular filaments within the canals in addition

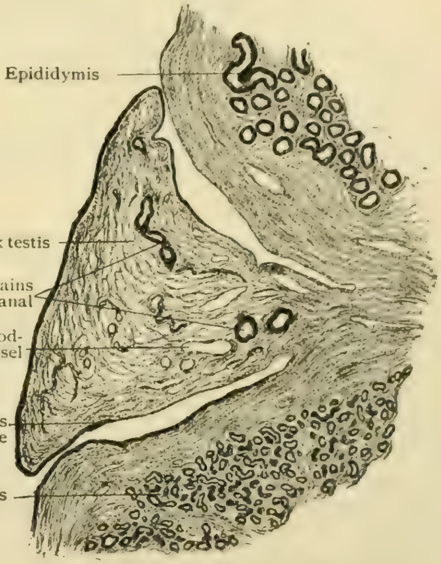
to the well-established end-plexuses on the external surface of their membrana propria. The existence of intratubal nerves, however, needs further evidence.

THE APPENDAGES OF THE TESTICLE.

Under this heading are included several vestigial structures that remain for a variable period, some throughout life, as more or less conspicuous bodies attached to the testis or to the epididymis. They claim attention not only on account of their interesting morphological relations, but also since they may become the seat of cystic and other pathological changes. The most important are (1) the *appendix testis*, (2) the *appendix epididymidis*, (3) the *paradidymis*, and (4) the *vasa aberrantia*.

The **appendix testis**, often called the *unstalked* or *sessile hydatid*, is a small but fairly constant body (being present in over 90 per cent. according to Toldt) from 5–10 mm. in length and less than half as much in breadth, fixed to the upper pole of the testis close to or slightly overlaid by the globus major (Fig. 1650). The term "hydatid" is inappropriate, since the body is solid and not vesicular and its form is irregular. Its free end often presents a shallow, funnel-like depression surrounded by a dentated margin, the whole suggesting the fimbriated end of the oviduct in miniature, a resemblance supported by the embryological significance of the appendage as the remains of the cranial end of the Müllerian duct (page 2038) overgrown and enclosed by connective tissue. In structure the appendage consists of a vascular connective-tissue stroma in which lies embedded a minute canal, of variable size and extent, lined with columnar epithelium. Usually the canal ends blindly, but in exceptional cases it may open on the free surface.

FIG. 1661.



Sagittal section of appendix testis. × 25.

Inconspicuous additional **appendages of the rete testis** have been described by Roth and by Poirier, which consist of blind tubules that extend from the testicle into the lower end of the globus major, either lying buried within the latter behind the testis or projecting as small elevations on the free surface. They probably represent the remains of Wolffian tubules that failed to retain their connection with the canal of the epididymis (Wolffian duct).

The **appendix epididymidis**, or *stalked hydatid*, much less constant than the sessile one (27 per cent. according to Toldt), appears as a small pyriform body (from 3–4 mm. in length) attached to the upper pole of the globus major (Fig. 1650). This appendage is variable in form, size, and number (since two or more may be present), and corresponds with the pedunculated hydatid in the female, both bodies probably being derived from anlages of the tubules of the Wolffian body, although their origin is still a subject of discussion and by some referred to the Müllerian duct.

According to Toldt, an additional minute body (*lower paradidymis*), consisting of a single convoluted tubule, is sometimes found, even in aged subjects, behind the head of the epididymis, but in front of the veins. It may be isolated, connected with the canal of the epididymis, with the rete testis, or with both, these variable relations being explained by its probable nature as an efferent duct that has become completely or partly disconnected. This tube is frequently the seat of cysts which,

when the canal retains its connection with the epididymis or testis, may contain spermatozoa.

The **paradidymis**, or *organ of Giraldès*, consists of an irregular group of blind tubules (from 5–6 mm. in extent) that lie within the lower end of the spermatic cord, above but close to the globus major and always in front of the venous plexus. This organ (*upper paradidymis* of Toldt) is regarded as representing a partial persistence of the rudimentary tubules of the Wolffian body (page 1936) and is, therefore, the homologue of the paroöphoron. It is essentially a fœtal structure, usually entirely disappearing after the first few years of childhood. The tubules (from .1–.2 mm. in diameter and lined with ciliated epithelium) rarely give rise to cysts.

The **vasa aberrantia** (**ductuli aberrantes**) include tubular appendages—usually two, but sometimes only one—that extend for a variable distance within the epididymis and end blindly. The *upper* and shorter one is attached to the rete testis and pursues a downward course within the epididymis. The *lower* and larger one, often 30 cm. (12 in.) or more in length, passes upward from the lower part of the canal of the epididymis and consists of one or more convoluted tubes of considerable size. Both are to be regarded as probably originating from the Wolffian tubules.

PRACTICAL CONSIDERATIONS: THE TESTICLES.

Monorchism—the absence of one testicle (not to be confounded with cryptorchism, *vide infra*)—has been shown at autopsies to occur occasionally. It is attended by no symptoms.

Anorchism—the absence of both testicles—may be inferred when the scrotum is also absent or incompletely developed, and there is a rudimentary condition of the external genitalia; impotence, sterility, and the physical and mental attributes of eunuchism appear later.

Arrest of descent of one or both testicles (page 2040) may occur at any point between the lower border of the kidney and the bottom of the scrotum. The chief forms are: (*a*) *Abdominal Retention* (cryptorchism, unilateral or bilateral): the testicle may be applied to the posterior abdominal wall in close relation to the lower, outer border of the kidney; it may be provided with a long mesorchium, allowing it to move freely in the abdominal cavity, or it may lie in the iliac fossa close to the internal ring; (*b*) *Inguinal Retention:* the testicle may be arrested at the internal ring, in the inguinal canal, or at the external ring. It is usually extremely mobile until subject to repeated attacks of inflammation and fixed by adhesion. (*c*) *Cruro-Scrotal Retention:* the testicle may pass through the external abdominal ring, but fail to descend completely, lying in close relation to the ring or at a varying distance below it. Of these, inguinal retention is the most common. Adhesions from prenatal peritonitis in *a*, small size of the external ring in *b*, and undue shortness of the cord or of one of its constituents in *c* have been thought to explain some of these cases.

Aberrant descent (ectopy), in which the testicle leaves its normal route, may occur in one of several forms. (*a*) In *peno-pubic ectopy* the testicle is found beneath the skin of the abdomen above the root of the penis. (*b*) In *perineal ectopy* the testicle is felt as a freely movable, ovoid tumor, sensitive to pressure, lying on one side of the central raphe, and placed in front of the anus; the cord can often be traced from the tumor to the external abdominal ring. The overlying skin sometimes exhibits rugæ, and the corresponding side of the scrotum is often atrophied. (*c*) *Femoral ectopy* appears as a movable tumor exhibiting the physical characteristics of the testicle and the peculiar sensitiveness. Its position is that of complete femoral hernia or of the inflammatory swellings which so commonly affect the glands overlying the saphenous opening.

Of these, perineal ectopy is the usual form. Irregular development of the gubernaculum may explain *a* and *c*, as certain of the fibres of the genito-inguinal ligament run to the pubic, lower inguinal, and inguino-femoral regions, and their over-development might draw the testicle in front of the pubes or into the femoral canal. Exceptional attachments (which have been shown to exist) of the gubernaculum below to the tuber ischii or sphincter ani may account for at least some of the cases included in *b*.

In its bearing on the development and course of hernia and inflammation the relation of misplaced testicle to the peritoneal pouch, which accompanies it, is of great importance. This pouch may remain open, communicating freely with the general peritoneal cavity, thus enhancing the probability of the formation of hernia or of the extension of inflammation; it may be closed above but open below the testicle, favoring the development of hydrocele; it may be obliterated. Exceptionally, especially when the testicle is retained but the vas has partly or completely descended, the funicular process of the peritoneum may extend as an open pouch to the bottom of the scrotum, thus allowing a hernia to pass far beyond the position of the retained testis.

Occasionally the testicle is found in the front of the scrotum (the epididymis anterior and the vas deferens in front of the other constituents of the cord), as if it had made a semi-revolution on its vertical axis (*inversion* of the testicle). The possibility of the existence of this anomaly emphasizes the propriety of determining by palpation and by the test of translucency the position of the testicle before tapping for hydrocele; or, if these fail, of evacuating the fluid by incision instead of with a trocar.

Torsion (axial rotation) of the testicle, including the spermatic cord,—also on its longitudinal axis,—is an accident which usually affects imperfectly descended testicles, but is not confined to them. The cause is probably a congenital malformation, since, as Owen has pointed out, a testis properly placed in the scrotum and possessed of a normal mesorchium cannot be twisted. The twist may be in either direction,—to the right or to the left,—and in accordance with its extent and the degree of constriction to which the vessels are subject the symptoms are slight or severe. In slight cases the epididymis alone becomes infiltrated. In severe cases the entire gland with the epididymis becomes gangrenous.

Orchitis—as distinguished from epididymo-orchitis—is rare as a result of either trauma or infection, owing to the firm support the gland receives from the tunica albuginea and to the free movement of the testicle, not only within its serous tunic, but also within the scrotum, and, on the other hand, to the fact that septic organisms gaining access to the ejaculatory duct, or brought to the gland in the general circulation, are in either case arrested and given the opportunity to multiply in the neighborhood of the epididymis.

The intimate investment of the testicle by the tunica vaginalis, which is complete except at the point of entry and emergence of the vessels at its posterior border, but which leaves the whole hinder aspect of the epididymis without a serous covering, determines the frequency with which serous effusion (acute hydrocele) occurs in contusions or inflammations of the testicle proper as compared with those of the epididymis.

The similar close investment of the former by the tunica albuginea accounts for the relatively greater pain and slower swelling in orchitis. It also brings about, when by ulceration a communication with the cutaneous surface has been established, the slow protrusion of the swollen and infected testicular substance, known as *hernia* or *fungus testis*, analogous to *hernia* or *fungus cerebri*, the physical conditions—enclosure of peculiarly soft and yielding tissue within a dense and resisting membrane—being similar in the two instances. The sickening pain following contusion of the testicle, or often associated with orchitis, is due to pressure upon or irritation of testicular nerves which, by way of the spermatic plexus, communicate with the aortic and solar sympathetic plexuses. A similar communication with the renal plexus explains the testicular pain and retraction accompanying the passage of a renal calculus. The primary development of the testicle in the vicinity of the tenth dorsal vertebra has determined its chief innervation from the tenth dorsal segment of the cord (Head) and thus its relation to the posterior divisions of the lower dorsal and the lumbar nerves which causes the "backache" so commonly felt in orchitis, in the presence of a solid tumor of the testicle, or after injecting the sac of a hydrocele. The epididymis derives its nerve-supply chiefly from the pelvic plexus, which also supplies the vas deferens and the seminal vesicles. As it communicates with the spermatic plexus, the same symptoms may be associated with an epididymitis; but as swelling is less resisted and pressure is therefore less, and as the communication with the great

abdominal plexuses is more indirect, "testicular nausea" is less pronounced and is often absent.

Epididymo-orchitis is usually of infectious origin, the gonococcus and the bacillus tuberculosis being the micro-organisms most often found, although the inflammation may occur in the course of any infectious disease, as scarlatina, mumps, or typhoid fever.

The direct channel offered by the vas deferens explains the localization of the gonorrhœal infection (page 1954); the division of the spermatic artery at the epididymis, and the fact that the arteries of the epididymis are smaller and more tortuous than those of the vas or of the testicle, and the consequent slowing up of the blood-current (favoring bacterial growth), may account for the preference shown the epididymis by the general infections. Syphilis more often affects the testicle itself because syphilitic orchitis is usually a late manifestation ; the disease at this stage shows its customary predilection for fibrous and connective-tissue structures, and, beginning, as it often does, as a cellular infiltration of the tunica albuginea, it follows the trabeculæ into the interior of the gland. When syphilis affects the testicle during the secondary stage, it behaves like other infections and is, at least at first, localized in the epididymis.

A certain number of cases of epididymo-orchitis follow *strain*, there having been no known infectious cause and no direct trauma. They have the usual symptoms,—apt to be slight at first,—and occur with much greater frequency on the left than on the right side. Two of various theories as to their production are interesting from the anatomical stand-point. (*a*) *Violent contraction of the cremaster muscle*, which, by suddenly jerking the testicle against the pillars of the external ring, causes bruising of the gland-tissue and the epididymis. The cremaster is certainly capable of vigorous contraction. Thus it is not rarely observed that direct trauma of the testicle is followed by marked retraction of the organ, so that it may be drawn into the inguinal canal or even into the abdominal cavity. Even in severe pain, such as that which accompanies renal colic, the testicles are frequently found in close apposition to the external ring, while any one can observe the contraction of the cremaster by noticing the motion of one or both testicles during the passage of a catheter. Certain cases of chorea of the testicle are at times observed when this organ is moved by the cremaster with considerable rapidity and violence. (*b*) *Rupture of some of the veins of the spermatic plexus*, which are peculiarly under the influence of intra-abdominal pressure, are provided with but few and imperfect valves, are feebly supported by the surrounding tissues, and hence are especially subject to disease. Thus varicosity of these veins is one of the most common surgical affections, and the effect of the contraction of the abdominal parietes and the diaphragm upon the dilated veins is so marked that succussion on coughing or straining in any way is sufficiently distinct to simulate that of an omental hernia. Given, then, a sudden and violent increase of pressure in these vessels, it is perfectly possible to conceive that rupture may occur, even although they are healthy ; this is, of course, more probable if they are weakened and dilated. Such a rupture would naturally take place in the cord, in the epididymis, or even in the substance of the testicle. And, if the theory of venous rupture from pressure is correct, we should expect the left testicle to be more frequently involved (as the veins of this side are more frequently varicose), and the pain to be slight at first and gradually increase as more blood was effused and inflammatory symptoms developed.

It is not improbable that both of these factors are concerned in the production of this form of epididymo-orchitis.

The various *tumors* of the testicle have no especial anatomical significance except as to the routes by which they involve the nearest lymph-nodes (*vide infra*).

Castration, unless modified by extensive malignant disease, is usually done by means of an incision which may be placed over or just beneath the external abdominal ring or even lower, and extends through the scrotal tissues, but not into the tunica vaginalis. The gland with its coverings may, if normal, easily be shelled out and the cord isolated, transfixed, ligated, and divided. If the vascular constituents of the cord are ligated separately, three arteries—the cremasteric, the spermatic, and the deferential—must be tied. The deferential artery is found close to the vas, and

with it are a few veins; the cremasteric lies to the outer side of the cord, near its surface; the spermatic is in front of the cord, surrounded by the anterior group of veins, and can scarcely be distinguished from them. Each artery should have a separate ligature, but the two sets of veins may be tied *en masse*; the divided cord should be secured with artery forceps until the end of the operation.

When the cord is extensively involved, the incision should be extended up along Poupart's ligament. It is deepened to the peritoneum, which is stripped up, allowing access to the lymph-nodes of the pelvis. When the lymphatic involvement extends upward beyond reach, it may be attacked through a transperitoneal opening. The nodes into which the lymph-vessels of the cord pass completely surround the aorta. There is, moreover, one lying upon the external iliac artery which probably will be involved.

Hydrocele—an effusion into the tunica vaginalis—may begin in the acute form (*vide supra*), may result from disease of the cord, the epididymis, or—more particularly—the testis, or may appear to be "idiopathic,"—*i.e.*, with no discoverable preceding pathological condition of the scrotal contents. In the majority of such cases it is thought (Jacobson) that the effusion of fluid commences passively and without any irritation or inflammation to begin with, the causes predisposing to its production being the pendent position, the less vigorous condition of the cremaster and dartos, feebler cardiac circulation, deficiency of tone in the scrotal blood-vessels and lymphatics, together with, perhaps, a tendency to venous congestion from hepatic and renal degeneration. All these conditions, which combine to bring about a passive effusion, naturally begin to be most active in middle life, this being the age when the ordinary hydrocele of the tunica vaginalis is most frequently met with. After a while, as the fluid increases in bulk, it becomes, from exposure to friction, etc., liable to irritation and to inflammatory changes, which show themselves in both the fluid and the tunica vaginalis itself.

The anatomical relations of the effusion to the testicle and epididymis, the characteristic slow increase in size of the affected side of the scrotum, the effacement of the rugæ, the drag upon the cord, and the referred pains sometimes caused by it have been sufficiently explained (*vide supra*).

Congenital hydrocele depends for its existence upon the maintenance of a communication between the tunica vaginalis and the abdominal cavity. The funicular portion of the tunic does not become obliterated. The fluid may come from the general abdominal cavity or may be exuded from the vaginal tunic. It may develop in early infancy or not until later in life.

Infantile hydrocele is an effusion into a sac formed by more or less of the unobliterated funicular portion of the vaginal tunic. This sac is closed from the peritoneal cavity above and communicates with the tunica vaginalis testis below.

Bilocular hydrocele is a comparatively rare form of infantile hydrocele. The funicular portion of the tunica vaginalis is commonly obliterated at the internal ring. Below this the whole tunica vaginalis may be patulous, or it may be closed just above the position of the testis. As the fluid accumulates, sacculation develops, the tumor extending either backward and downward into the pelvis or more commonly upward and inward between the abdominal muscles and the peritoneum.

Encysted hydrocele of the cord, or funicular hydrocele, consists of an accumulation of fluid within an unobliterated portion of the funicular portion of the tunica vaginalis. This accumulation is closed from the peritoneal cavity above and from the tunica vaginalis testis below. The hydrocele may be unilocular, bilocular, or multilocular, in the latter case forming a series of small cysts along the course of the cord. These cysts may be placed in the inguinal canal, and are more common on the right side. They are usually observed in children, and may be complicated by hernia.

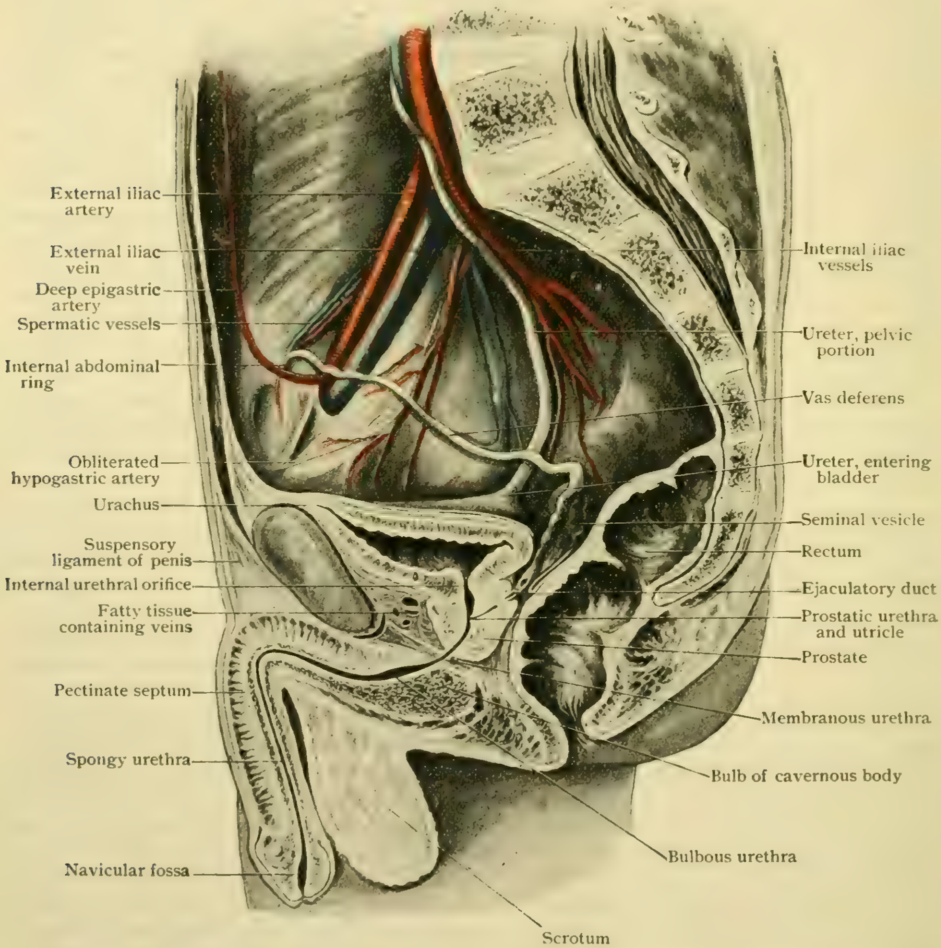
THE SPERMATIC DUCTS.

The spermatic ducts are two tortuous canals, one on either side, that connect the epididymi with the urethra and thus provide channels for the escape of the products of the sexual glands. Each duct is divisible into the *vas deferens* and its *ampulla* and the *ejaculatory duct*; at the upper end of the latter the spermatic duct is connected

with the *seminal vesicle*, a saccular organ representing an outgrowth from the main canal.

The Vas Deferens.—This tube (**ductus deferens**) extends from the epididymis to the ejaculatory duct and includes almost the entire length of the spermatic duct, with a diameter of from 2–3 mm. Beginning at the globus minor as the direct continuation of the convoluted canal of the epididymis, the vas deferens is at first also very tortuous, and by its windings forms a tapering mass (**pars testicularis**) about 2.5 cm. in length. From the latter the seminal duct is prolonged upward along the inner side of the epididymis and behind the testis, becoming progressively less wavy and

FIG. 1662.



Dissection of sagittally cut pelvis, showing relations of organs after fixation by formalin injection.

of larger and more uniform size (3 mm.) as it enters the spermatic cord. Although the apparent entire length of the canal is about 30 cm. (12 in.), its actual extent is some 45 cm. (18 in.) on account of the tortuosity of its first part.

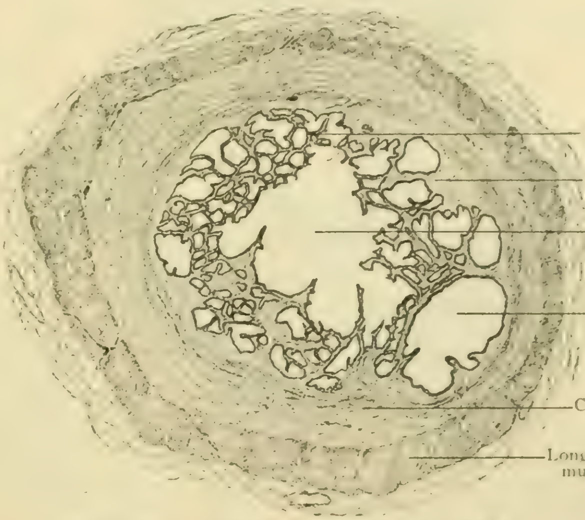
Within the spermatic cord (**pars funicularis**), accompanied by the deferential artery and the posterior plexus of veins (Fig. 1670), the vas occupies a position behind the other constituents of the cord, and may be recognized by the hard, cord-like feel imparted by its thick fibro-muscular wall. The duct ascends almost vertically to the pubic spine, and on gaining the abdominal wall passes through the external abdominal ring, traverses the inguinal canal, and completes its passage of the body-

wall by going through the internal abdominal ring. After emerging from the latter it parts company with the spermatic vessels, hooks over the external and posterior surface of the deep epigastric artery, crosses obliquely the external iliac vessels and the pelvic brim, and enters the true pelvis. From its entrance at the internal ring the vas lies within the subserous tissue immediately beneath the peritoneum, through which it may usually be traced.

During its further course (**pars pelvina**) the duct at first lies along the lateral pelvic wall, directed backward and slightly upward towards the ischial spine, crossing to their inner or median side the obliterated hypogastric artery, the obturator nerve and vessels, the vesical vessels, and the ureter. After passing in front and to the inner side of the ureter, the duct turns sharply downward and inward and traverses the subperitoneal tissue covering the pelvic floor to reach the vicinity of the seminal vesicle in the space between the posterior surface of the bladder and the rectum.

Where in relation with the seminal vesicle, the vas deferens presents a somewhat flattened spindle-form enlargement, known as the **ampulla** (**ampulla ductus deferentis**), from 3–4 cm. in length and from 7–10 mm. in its greatest width, that passes in front and then along the median side of the seminal vesicle in its descent to the prostate gland. The contour of the ampulla is uneven and humpy, especially after removal of the investing fibrous tissue, due to the sacculations and tortuosity of the canal (Fig. 1666) and the short diverticula that pass off from the main duct at various angles, thus anticipating in simpler form the arrangement seen in the seminal vesicle.

Fig. 1663.



Cross-section of ampulla of spermatic duct. 18.

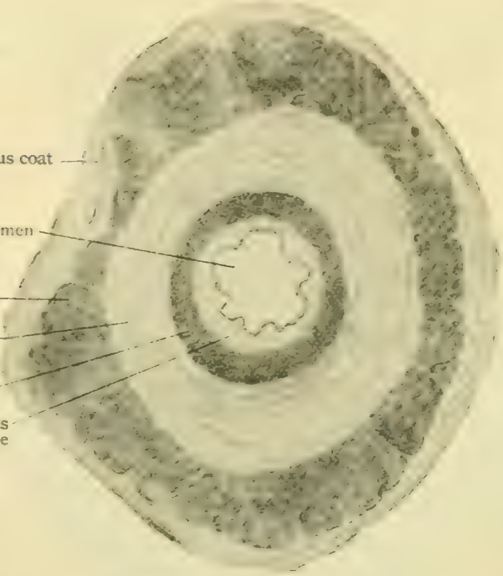
Just before reaching the latter the vas usually describes a curve directed backward and outward (Fig. 1469) and occupies the crescentic recto-vesical (sacro-genital) peritoneal fold. At the lower end of the ampulla the vas loses its sacculations and again becomes a narrow tube which, joining with the passage from the seminal vesicle, is continued as the ejaculatory duct that traverses the substance of the prostate gland and terminates in the urethra at the side of the prostatic utricle. The ampullæ of the two sides converge as they descend, so that their lower ends are almost in contact where the spermatic duct receives the seminal vesicles. The intimacy of the relation between the vasa deferentia and the bladder varies with the condition of the latter organ. With the increased volume incident to its distention, the posterior surface of the bladder is pressed against the spermatic ducts; on the other hand, when the bladder is empty, only the lower parts of these structures are in close relation with the vesical wall.

The **ejaculatory duct** (**ductus ejaculatorius**), the terminal segment of the spermatic canal and apparently formed by the union of the duct of the corresponding seminal vesicle and the vas deferens, is really the morphological continuation of the latter, from which the seminal vesicle is developed as a secondary outgrowth. Beginning with a diameter of from 1.5–2 mm., the ejaculatory duct enters the posterior surface of the prostate (Fig. 1680), defining the lower limit of the middle lobe, and after a course from 18–20 mm. (about ¾ in.) in length, ends in the urethra by a minute elliptical opening situated on the crest at the side of the orifice of the prostatic

utricle (Fig. 1632). In rare cases the ducts of the two sides may join before reaching the urethra and communicate with the latter by a common aperture, or they may open independently into the prostatic utricle. In the descent of the duct the lumen of its upper and middle thirds is modified by a series of four or five diverticula of decreasing size (Felix). At such levels the usual oblique oval outline of the canal is amplified by the irregular dilatations.

Structure of the Spermatic Duct.—The *vas deferens* is distinguished by the conspicuous thickness of its wall (from 1–1.5 mm.) that encloses a relatively narrow lumen (.5–.7 mm.) and confers upon the canal its characteristic hard, cord-like feel. The wall consists of three coats, the mucous, muscular, and fibrous (Fig. 1664). The *mucous coat* is clothed with epithelium which in the vicinity of the testicle and for an uncertain distance beyond resembles that lining the duct of the epididymis, consisting of an imperfect double layer of tall, columnar ciliated cells. Throughout the greater part of the duct, however, the cells are lower and without cilia and contain numerous particles of pigment. The tunica propria possesses a dense felt-work of elastic fibres intermingled with bundles of fibrous tissue. The robust *muscular coat* (from .8–1.2 mm. in thickness) constitutes approximately four-fifths of the entire wall, and consists of pale fibres arranged as an outer longitudinal, a middle circular, and an inner longitudinal layer, the latter being less well developed than the outer and middle strata. The external *fibrous coat* that invests the muscular tunic is thin and serves to connect the spermatic duct with the surrounding structures.

FIG. 1664.



Cross-section of vas deferens. × 20.

In its general structure the *ampulla* corresponds with the vas deferens, the walls of this part of the duct, however, possessing a much thinner muscular coat, in which the inner longitudinal layer is wanting, and a mucosa modelled by numerous ridges and depressions (Fig. 1663) and covered with a single layer of low, columnar, non-ciliated epithelial cells.

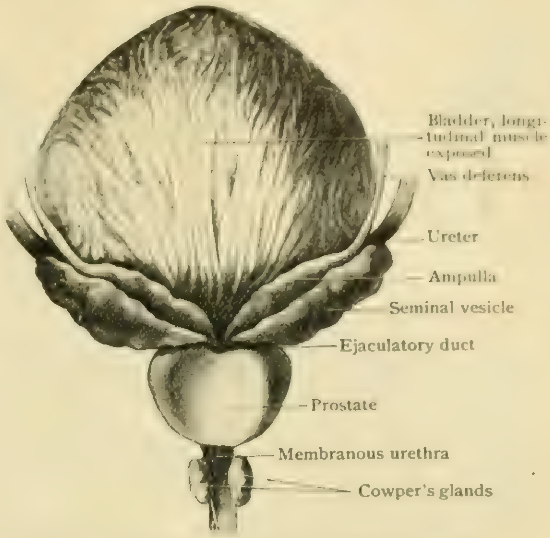
The *ejaculatory duct* likewise possesses a structure essentially the same as in other parts of the spermatic canal. Its walls, however are thinner than those of the ampulla, this reduction being due to the diminished thickness and incompleteness of the muscular coat, which on nearing the urethra becomes attenuated and mingled with fibrous tissue. In some places the epithelium of the duct consists of a single and in others of a double layer of columnar cells until within a short distance from the termination of the canal, where it assumes the transitional character of the epithelium lining the prostatic urethra.

THE SEMINAL VESICLES.

The seminal vesicles (**vesiculae seminales**) are two sacculated appendages of the vasa deferentia that lie behind the bladder and in front of the rectum. Flattened from before backward, their general shape is pyriform, with the larger ends, or *bases*, directed upward and outward, the long axes converging towards the mid-line as the

organs taper, often abruptly, at their lower ends to join the spermatic ducts. Usually from 4–5 cm. in length, sometimes much longer and relatively slender and at others short and broad, the seminal vesicles vary greatly in size and in the detail of arrangement of their component parts and not infrequently are markedly asymmetrical, the right one being often, but not invariably, the larger.

FIG. 1665.

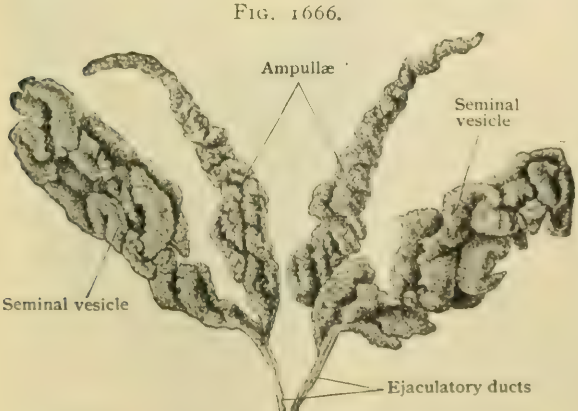


Dissection showing seminal ducts and vesicles, prostate and Cowper's glands; viewed from behind.

Divested of the fibro-muscular tissue that invests the organ as its *capsule* and blends its divisions into a tuberculated common mass, each vesicle may be resolved into a *chief duct* and *diverticula*. The former—from 10–12 cm. (4–5 in.) in length—ends blindly after a more or less tortuous course, its terminal part often describing a sharp hook-like returning curve (Fig. 1667). From the main canal an uncertain number (from four to eight or more[1]) of blind tubular diverticula branch at varying angles and in different directions and by their tortuosities add to the complexity of outline. The lumen of the chief duct, as seen in section, is irregular, constrictions and dilatations following one another with little regularity. The opening of the duct into the lateral wall of the vas deferens is large in comparison with the terminal lumen of the ejaculatory duct, thus favoring the entrance of the secretions temporarily stored within the ampulla into the sacculated vesicle. The latter contains a fluid of light brownish color in which spermatozoa are nearly always found during the period of sexual activity.

Relations.—The seminal vesicles, together with the ampullæ, lie embedded within a dense fibro-muscular layer, so that their position remains relatively fixed, especially below, and to a certain degree independent of the changes in volume of the bladder and the rectum, neither of which they directly touch. Although when distended these organs are in close relation with the seminal vesicles, when empty the bases of the latter lie laterally and at some distance from both the vesical and rectal wall, surrounded by numerous veins that continue the prostatic and vesical plexuses. The lower half of the seminal vesicles and the ampullæ lie behind the fundus of the bladder, their axes approximately corresponding with the sides of the vesical trigone and embracing the retroureteric fossa, which part of the bladder-wall, when distended, may project between and even displace laterally the seminal ducts and vesicles. In passing from the slightly expanded bladder onto the rectum, the peritoneum covers the upper fourth of the seminal vesicles and the adjoining part of the ampullæ. The

FIG. 1666.



Cast of ampullæ and seminal vesicles, showing windings and sacculations of lumen. (*Pallin.*)

[1] Pallin: Archiv f. Anat. u. Entwick., 1901.

extent of this investment, however, varies with the depth of the recto-vesical pouch, which in turn depends upon the degree of distention of the bounding organs, the bladder and the rectum.

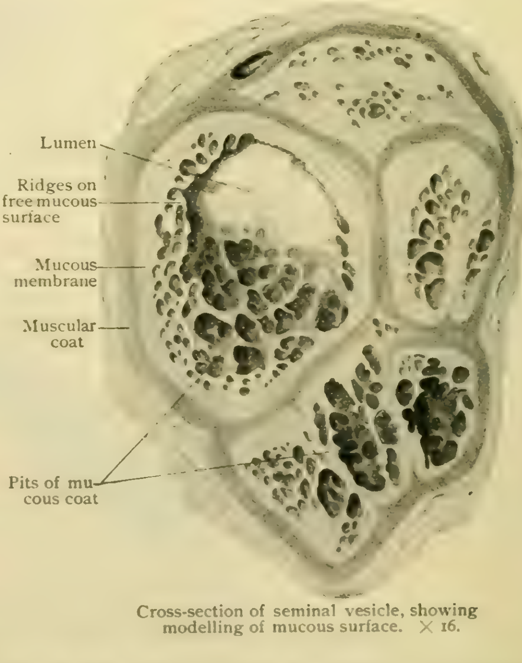
Structure.—In their general make-up the seminal vesicles closely resemble the ampullæ, possessing a robust muscular wall composed of an inner circular and an outer longitudinal layer of involuntary muscle. The mucous membrane is conspicuously modelled by numerous ridges and pits, so that the free surface appears honey-combed (Fig. 1668). The epithelial covering consists of a single or imperfect double layer of low columnar cells, many of which present changes indicating secretory activity. Although true glands are wanting within the seminal vesicles, the minute diverticula within the epithelium containing goblet-cells may be regarded as concerned in producing the peculiar fluid found within these sacs, which is of importance probably not only in diluting the secretion of the testicle and supplying a medium favorable for the motility of the spermatic filaments, but also in completing the volume of fluid necessary for efficient ejaculation (Waldeyer).

FIG. 1667.

Diagram showing course of main canal in preceding preparation: *a*, ampulla; *c*, seminal vesicle; *b*, ejaculatory duct. (*Pallin.*)

Vessels of the Seminal Ducts and Vesicles.—The *arteries* supplying the *spermatic duct* are derived chiefly from the deferential, a vessel of small size but long course that arises either directly from the internal iliac or from its vesical branches. On reaching the duct, just above the ampulla, the artery divides into a smaller descending and a larger ascending division. The former, in conjunction with accessory twigs from the middle hemorrhoidal and the inferior vesical arteries, generously provides for the ampulla, and the latter accompanies and supplies the vas deferens throughout its long course, finally, in the vicinity of the testicle, anastomosing with branches from the spermatic,—a communication of importance for collateral circulation. The twigs passing to the spermatic duct enter its wall and break up into capillary net-works within the muscular and mucous layers. The rich arterial supply for the *seminal vesicle* includes anterior and upper and lower branches, contributed by the deferential, the inferior vesical, and the superior and middle hemorrhoidal arteries. The minute distribution is effected by capillary net-works to the muscular and mucous coats.

FIG. 1668.



Cross-section of seminal vesicle, showing modelling of mucous surface. × 16.

The *veins* that follow the spermatic duct as the *deferential plexus*, and within the spermatic cord communicate with the pampiniform plexus, increase in size and

number as they approach the bladder and seminal vesicle ; in the vicinity of the latter they communicate with the seminal plexus and empty with the trunks of the posterior bladder-wall into the vesico-prostatic plexus. The posterior and lateral surfaces of the seminal vesicle are covered with a net-work of large veins (**plexus venosus seminalis**) that become tributary to the vesico-prostatic plexus.

The *lymphatics* of the seminal ducts and vesicles are numerous and arranged as deeper and superficial sets which form afferent trunks that pass to the internal iliac lymph-nodes. Those from the lower part of the seminal vesicles join the vesical lymphatics.

FIG. 1669.

Portion of wall of seminal vesicle in longitudinal section, showing pitting of mucous coat. × 45.

The **nerves** supplying the spermatic duct are derived from the hypogastric plexus of the sympathetic and consist chiefly of pale fibres destined for the involuntary muscle, some medullated fibres, however, being present. They accompany the greater part of the duct as the *deferential plexus* and have been traced into the muscular tissue and the mucosa. Within the former they form the dense *plexus myospermaticus* described by Sclavunos,[1] and are fairly plentiful within the mucous coat (Timofeew[2]). The nerves distributed to the seminal vesicles are very numerous and are derived in part directly from the hypogastric plexus (Fraenkel[3]), or through prolongations of the latter as secondary plexuses that follow the vesical and middle hemorrhoidal arteries.

PRACTICAL CONSIDERATIONS: THE SEMINAL VESICLES.

The seminal vesicles are rarely injured. The two forms of infection that are most common are the gonorrhœal and the tuberculous, although *vesiculitis* may be due to the ordinary staphylococci or to the colon bacillus. The channels of infection are comparable to those which convey disease to the epididymis; the ejaculatory ducts are continuous with the vas deferens and the vesicular duct, and the inferior vesical and middle hemorrhoidal arteries replace the spermatic artery. The tuberculous disease is, however, usually secondary to similar infection of the prostate or of the epididymis.

The anatomical relations of the vesicles to (*a*) the vesical trigonum, (*b*) the prostate and prostatic urethra, and (*c*) the rectum sufficiently explain the usual symptoms of acute vesiculitis : (*a*) frequent, painful, straining urination, hypogastric pain ; (*b*) priapism, painful emissions of blood-stained semen, occasionally epididymitis as a complication ; (*c*) painful defecation, rectal tenesmus, perineal and anal pain.

Rectal exploration (page 1692) will usually establish the diagnosis, as it will in *tuberculous vesiculitis*, in which condition, as in other forms—acute and chronic—of vesiculitis, there are apt to be pains referred to the loins, the hypogastrium, the

[1] Anatom. Anzeiger, Bd. ix., 1894.
[2] Anatom. Anzeiger, Bd. ix., 1894.
[3] Zeitsch. f. Morph. u. Anthrop., Bd. v., 1903.

anus and perineum, the hip-joint and sacro-iliac articulation of the affected side and the other side of the thigh, due to the association of the vesical, prostate, and pelvic plexuses with the lumbar and sacral nerves and their plexuses.

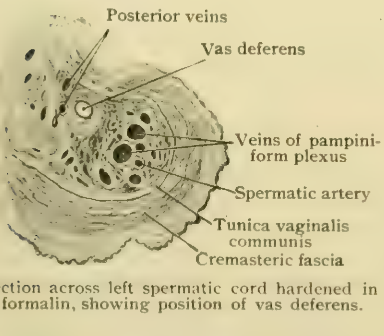
Vesiculitis may be a very serious condition, as it may result in abscess with perforation into the bladder within the limits of the peritoneal covering, or directly into the peritoneal cavity by way of the recto-vesical cul-de-sac. Cases of both these accidents have been reported. Pyæmia has also been known to follow a septic phlebitis of the adjacent venous plexuses; pelvic cellulitis with diffuse suppuration has resulted; and various troublesome abscesses burrowing between the bladder and rectum, and leaving fistulous tracts very slow to heal, have had their origin in suppurative vesiculitis. The chronic form may be associated with persistent vesical irritability, with some pain on emission of semen, with sexual excitability accompanied by premature ejaculation, and with persistent urethral discharge often mistaken for an ordinary gleet.

In chronic cases "massage" through the rectum has been advised and practised with some benefit in comparatively rare cases. The contents of the vesicles can sometimes be pressed through the ejaculatory ducts into the prostatic urethra and so evacuated. A similar expression of the normal secretion of the vesicles by fecal masses at stool is a fertile source of sexual hypochondriasis in young male neurasthenics, who, in consequence, imagine that they are afflicted with "spermatorrhœa."

THE SPERMATIC CORD.

In consequence of its migration from the abdominal cavity into the scrotal sac, the testicle is followed by its duct, vessels, and nerves through the abdominal wall into the scrotum. These structures, held together by connective tissue and invested by certain coverings acquired in their descent, form a cylindrical mass, known as the spermatic cord (**funiculus spermaticus**), that extends from the internal abdominal ring obliquely along the inguinal canal, emerging at the external ring, and thence descends vertically, beneath the integument, into the scrotum to end at the posterior border of the testicle. Most constant within the inguinal canal, where its diameter is about 15 mm. (5/8 in.), the thickness and length of the spermatic cord vary with the contraction of the cremasteric muscular fibres that control the position of the testicle.

FIG. 1670.



Section across left spermatic cord hardened in formalin, showing position of vas deferens.

The **constituents of the spermatic cord** are numerous and fall under four groups.

1. The *vas deferens* with its accompanying deferential artery and plexuses of veins, lymphatics, and nerves. The vas, surrounded by its artery and a venous plexus, occupies the posterior part of the spermatic cord, and is readily distinguished as a hard, round cord, from 2–3 mm. in diameter, by virtue of its unusually firm walls.

2. The *spermatic artery, veins, lymphatics, and nerves* belonging to the testicle proper. In contrast to the artery, the veins are particularly large and numerous and form the conspicuous *pampiniform plexus* which contributes in no small measure to the bulk of the cord.

3. The *coverings with their blood-vessels and nerves.* The coverings proper of the spermatic cord, contributed by the layers of the abdominal wall, correspond to those of the testicle, with the exception of the serous coat, which is wanting after closure of the processus vaginalis. From within outward they are: (*a*) the *infundibuliform fascia* (**tunica vaginalis communis**), a distinct layer continued from the transversalis fascia; (*b*) the *cremasteric fascia*, consisting of the muscular fibres prolonged from the internal oblique and transversalis, blended together by connective tissue. The muscular fibres descend as loops along the spermatic cord, especially on the posterior surface as far as the testicle, over the coverings of which they spread out in festoons and net-works; and (*c*) the *intercolumnar fascia*, a delicate sheet derived from the aponeurosis of the external oblique at the margin of the external abdominal

ring, is most distinct above, becoming thinner as it descends, until over the testicle it loses its identity as a distinct investment.

The coverings of the spermatic cord receive their blood-supply from chiefly the cremasteric branch of the deep epigastric artery; additional cremasteric twigs from the spermatic artery are distributed to the upper part of the cord, anastomosing with those from the first-named source. The nerves include the genital branch of the genito-crural and usually a twig along the front of the cord from the terminal branch of the ilio-inguinal.

4. The *rudimentary structures*, the remains of the processus vaginalis, the paradidymis, and sometimes the vas aberrans. After closure of the communication between the serous pouch and the peritoneal cavity, the processus vaginalis is represented by a delicate fibrous band (**ligamentum vaginale**) that may be traced, under favorable conditions, from the internal abdominal ring above through the spermatic cord as far as the upper margin of the tunica vaginalis below. The paradidymis (page 1950) lies within the lower end of the spermatic cord, immediately above the epididymis, or behind its upper pole, and in front of the venous plexus. Occasionally, when unusually developed, the vas aberrans (page 1950) may also extend into the lower end of the spermatic cord.

In addition to the foregoing coverings proper, the spermatic cord is enveloped by the skin, the superficial and the deep layer of the superficial fascia. The deep layer of the latter is important, being continuous above with the fascia on the abdomen and below, after investing the testicle, with Colles's fascia in the perineum.

PRACTICAL CONSIDERATIONS: THE SPERMATIC CORD.

The most frequent pathological condition associated with the cord (and not elsewhere described) is *varicocele*, an enlargement—with dilatation and lengthening—of the veins of the cord, occurring most frequently in young unmarried adults (fifteenth to twenty-fifth year) and on the left side (90 per cent. of cases).

The veins composing the spermatic plexus can be ranged in three groups, the most anterior of which has in its midst the spermatic artery, the middle the vas deferens, and the posterior is composed of those veins which pass upward from the tail of the epididymis. The anterior group is the one first affected, or, if the dilatation affects all the veins, is most extensively involved.

It is thought that varicocele often depends upon a congenital predisposition, but many anatomical reasons have been given to account (*a*) for its occurrence, and (*b*) for its greater frequency on the left side. (*a*) 1. The relative length and the vertical course of the veins. 2. The lax tissue surrounding them, so that (as with the long saphenous vein) they derive little support and their blood-current receives no aid from the presence or contraction of surrounding muscles. 3. Their large size as compared with the corresponding artery, so that the *vis a tergo* must be reduced to a minimum (Treves). 4. Their tortuosity, frequent anastomosis, and few and imperfect valves. 5. The pressure exerted upon them as they pass through the inguinal canal, not altogether unlike that experienced by the hemorrhoidal veins in their passage through the walls of the rectum. (*b*) 1. The veins in the left cord are much larger than those in the right. 2. The left testicle hangs lower than the right, so that the column of blood in the left veins is longer. 3. The left spermatic vein empties into the left renal vein at a right angle, whereas the right spermatic vein empties into the vena cava at an acute angle. 4. The left spermatic vein running behind the sigmoid flexure of the colon is constantly subjected to pressure from accumulation of fæces in the bowel.

In the operation for varicocele by excision of the pampiniform plexus the spermatic artery is often included, but gangrene of the testicle does not follow because of the escape of the deferential artery and of its free anastomosis with the spermatic and scrotal vessels.

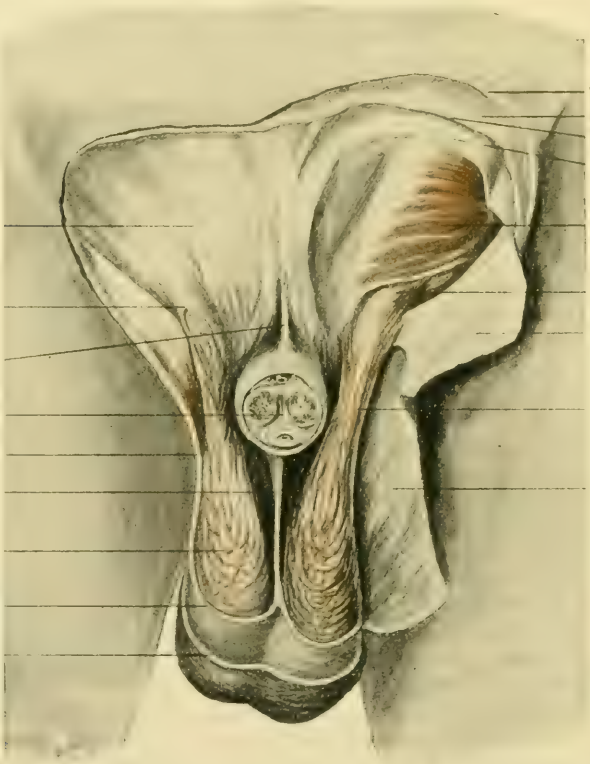
THE SCROTUM.

The scrotum, the more or less pendulous sac of integument that contains the testicles and the associated structures and the lower part of the spermatic cords, is attached to the under surface of the penis in front and to the perineum behind. Flat-

tened in front above, where attached to the penis and receiving the spermatic cords, its general form is pear-shaped and somewhat asymmetrical, since the left of the two oval swellings produced by the enclosed testicles and separated by a shallow longitudinal furrow is lower than the right owing to the position of the corresponding sexual gland. The scrotum varies, however, in form and appearance, even in the same individual, with the condition of the subcutaneous muscular tissue. When the latter is contracted, as after the influence of cold, the scrotum is drawn up and compact and its surface corrugated by numerous transversely curved folds ; when relaxed, it becomes smooth, flaccid, and pendulous.

Indications of its formation from two distinct parts are seen externally in the longitudinal *raphe*, which marks the line of fusion of the original halves and extends longitudinally from the urethral surface of the penis over the scrotum onto the peri-

FIG. 1671.



Dissection of spermatic cord and scrotum.

neum. Owing to the greater dependence of the left half of the sac, the raphe does not occupy a strictly median position, but is deflected towards the left. Internally evidence of the union of the scrotal halves is found in the sagittal partition (*septum scroti*) that is continued inward from the raphe and effectually divides the scrotum into a right and a left pouch. This septum, consisting of fibrous tissue rich in elastic fibres and the prolongations of the dartos muscle, is attached above to the root of the penis and the perineum, blending with the sheath of the bulbo-cavernosus muscle.

Since the labio-scrotal folds, which produce the scrotum or its homologue, the labia majora, according to sex, are developed (page 2041) independently of the coverings of the spermatic cord and the testicle derived from the musculo-fascial walls of the abdomen, the scrotum contributes additional envelopes for the enclosed structures. These envelopes are the *skin*, which is here thin, delicate, and very elastic, unusually dark, and beset with scattered crisp hairs and numerous sweat and sebaceous glands ;

and the *tunica dartos*, a layer of modified subcutaneous tissue—the superficial fascia—distinguished by the presence of numerous longitudinally disposed bundles of involuntary muscle-fibres and much elastic tissue and by the entire absence of fat.

The muscular tissue (*dartos muscle*), where best developed, as in the anterior and lateral walls of the scrotum, is sufficient in quantity to be recognized as a distinct layer, but so closely attached to the integument as to form practically a part of it. At the raphe, while some fibres follow the skin and remain superficial, the majority enter the septum, being especially well developed in the lower part, and at the attached upper border pass over into the dartos of the penis and the perineum. The numerous bundles of elastic tissue within the tunica dartos in the upper and anterior part of the scrotum become condensed into robust bands which efficiently aid in supporting the scrotal sac, since they are continued laterally at the sides of the penis and over the spermatic cords into the superficial fascia of the abdomen, and in the mid-line blend with the suspensory ligament of the penis. Those on the posterior surface are attached over the pubic and ischial rami.

Enumerated from without inward, the layers interposed between the surface of the scrotum and the serous cavity surrounding the testis are: (1) the *skin*, (2) the modified *superficial fascia* or *tunica dartos*, (3) the *intercolumnar fascia*, (4) the *cremasteric fascia*, (5) the *infundibuliform fascia*, and (6) the *tunica vaginalis*. Of these the first two alone, strictly considered, are contributed by the scrotum, the remaining layers being derived from the deeper structures of the abdominal wall and associated with the descent of the testicle. The connection between the tunica dartos and the underlying intercolumnar fascia is by no means firm, being effected by a loose layer of areolar tissue, devoid of fat, that permits a ready separation, particularly in front, between the external scrotal envelope and the coverings proper of the testis. Beneath the posterior surface of the scrotum the connection is firmer (Disse). This separation, however, is arrested at the lower part of the scrotum, owing to the presence of the *scrotal ligament* (Fig. 1723), a mass of fibrous tissue that anchors the lower end of the tunica vaginalis and the testicle to the external envelopes.

With the exception of the serous coat, the tunica vaginalis, these coverings have been considered in connection with the spermatic cord (page 1960); it remains, therefore, to describe more fully the serous coat to which incidental reference has been made (page 1941) in its relations to the testis and the epididymis.

The production of an isolated, closed serous sac within each half of the scrotum results from partial obliteration of the serous pouch, the processus vaginalis, that during fœtal life extends from the general peritoneal cavity into the scrotum in anticipation of the descent of the sexual gland.

The **tunica vaginalis** (**tunica vaginalis propria testis**), in correspondence with other serous membranes, consists of a parietal and a visceral portion, the latter providing an extensive but incomplete investment for the testis and the epididymis and the former lining the serous cavity into which these organs, thus covered, project. With the exception of small spaces caused by the elevation of the epididymis, especially of the globus major, these two layers are practically in contact and separated by only a capillary cleft. Whatever space exists is filled by a clear straw-colored serous fluid.

In addition to walling the cavity, the *parietal layer* invests the spermatic cord for about 12 mm. above the testicle and the blood-vessels behind, and then is continued into the visceral layer along the line of reflection that passes over the back of the testis to its lower pole on the one side and along the posterior surface of the epididymis on the other, thus leaving an intervening uncovered strip as a passage-way for the duct, vessels, and nerves.

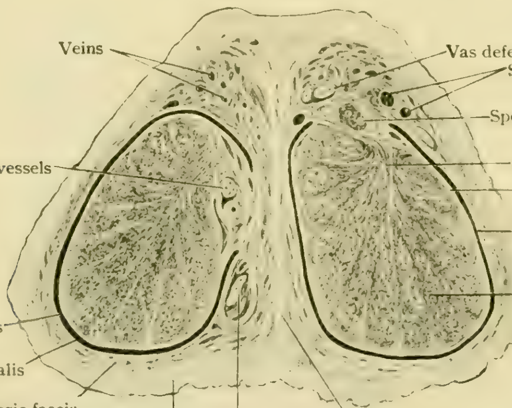
From the line of reflection the thin *visceral layer* completely invests the testis and the epididymis, adhering intimately with the tunica albuginea, and dipping deeply between these organs to form the *digital fossa* (**sinus epididymidis**). This pocket (Fig. 1650), the entrance to which is narrowed by two transverse folds (**ligamenta epididymidis superior et inferior**), may be so deep that the serous membrane at its bottom is in contact with that reflected from the median side of the testicle. Numerous bundles of involuntary muscle—the *m. cremaster internus* of Henle—radiate from the scrotal ligament at the lower part of the scrotum to spread out between the

parietal layer of the tunica vaginalis and the infundibuliform fascia, extending upward into the spermatic cord.

Vessels.—The *arteries* supplying the scrotum,—as distinguished from those destined for the spermatic cord and the sexual gland and associated structures,—although of small size, are derived from different sources. Those distributed to the front and sides are the anterior scrotal branches from the deep external pudics, supplemented above by twigs from the superficial external pudics. The back of the scrotum and the septum are supplied by the posterior scrotal arteries, superficial branches from the internal pudics. Free communication exists not only between the vessels of the two sides across the mid-line, but also between the anterior and posterior branches at the sides. The scrotal arteries anastomose with twigs from the obturator and internal circumflex, as well as with those from the cremasteric artery.

The *veins*, numerous and plexiform in arrangement, form trunks that follow the general course of the chief arteries, becoming tributary to the external saphenous or the femoral and the internal pudic veins. They anastomose freely with the adjoining venous paths of the penis, perineum, and pubic region.

Fig. 1672.



Section across formalin-hardened scrotum, showing lower end of spermatic cords and testes in section.

The *lymphatics* of the scrotum are very numerous and form a superior and an inferior group of vessels, all of which lead to the median group of superficial inguinal lymph-nodes. Frequent communications occur with those of the penis and perineum, but only sparingly with the deep lymph-tracts within the spermatic cords.

The **nerves** supplying the scrotum are derived from both the lumbar and sacral plexuses. Those from the former source are distributed to the front and sides of the scrotum and include cutaneous twigs from the genital branch of the genito-crural nerve, usually reinforced by twigs from the ilio-inguinal that end in the integument in the vicinity of the root of the scrotum. Those from the sacral plexus supply the posterior surface of the scrotum and are from the perineal or inferior pudendal branches of the small sciatic nerves and the anterior or external superficial perineal branches of the pudic nerves. Sympathetic fibres accompany the cutaneous nerves for the dartos muscle.

PRACTICAL CONSIDERATIONS: THE SCROTUM.

The scrotum, from a practical stand-point, may be studied as if composed of two layers, an *external*, made up of the skin and dartos, and an *internal*, consisting of the three coverings—fascial, muscular, and aponeurotic—derived from the abdominal wall, the infundibuliform, cremasteric, and intercolumnar.

As the testes are safer from injury in a loose pouch, in which they can readily glide away from threatened trauma, the scrotum is redundant (more so on the left

side on account of the greater length of the left spermatic cord) and lax. Advantage of these facts is taken in certain operative procedures, as in making the flaps in Roux's operation for vesical exstrophy, or excising a portion of the scrotum (to secure firmer support for the vascular structures of the cord) in varicocele.

The redundancy, thinness, and elasticity of the skin and the laxity of the fatless areolar tissue connecting the internal and external layers combine to favor: (*a*) marked discoloration and great extravasation of blood in cases of hemorrhage from the vessels between the two layers; hence in orchitis leeches are applied, not over the scrotum, but in the line of the cord in the groin; (*b*) extreme distention, as in large scrotal herniæ, in hydrocele, in bulky testicular tumors; (*c*) extensive œdema in general anasarca, as a result of pelvic venous thrombosis, or accompanying an infectious cellulitis or an extravasation of urine, which, when it proceeds from a solution of continuity anterior to the triangular ligament, is directed by Colles's fascia into this cellular space between the two layers. The thinness of the scrotal skin, increased when it is distended, makes it, in spite of its vascularity, very susceptible to gangrene from pressure, as in "strapping" an inflamed testicle, or from underlying cellulitis.

The longitudinal contractile fibres of the dartos draw the redundant skin into transverse rugæ which, by retaining extraneous dirt and the secretions of the sweat-glands and sebaceous follicles, become often the starting-point of eczema, of mucous patches, or even (as in "chimney-sweep's cancer") of epithelioma. The contractility of the dartos is marked in young and robust persons, and is increased by cold, by sexual excitement, and by light friction. It is lessened in old age, by debility, or by continued warmth and moisture, the scrotum, in the presence of those conditions, becoming smooth, elongated, and pendulous. It is useful in aiding the scrotum to regain its normal size after distention, as following the tapping of a hydrocele or the removal of a tumor. On the other hand, the dartos tends to invert the edges of a scrotal wound (as the platysma does those of a wound of the neck), and warm applications may therefore be useful before a scrotal incision is sutured.

The muscular (cremasteric) element of the inner layer gives it contractility, and the intimate connection between it, the deeper (infundibuliform) plane of fascia, and the parietal layer of the tunica vaginalis enables it to elevate the testicle with its coverings when it is excited to contraction. This may be done (*cremasteric reflex*) by drawing the finger-nail over the skin of the thigh a little below Poupart's ligament, the sensory impression being conveyed from the skin through the crural branch, and to the cremaster through the genital branch, of the genito-crural nerve.

The infundibuliform (internal spermatic) fascia, by its close relation to the postero-inferior portion of the testicle, on the one hand, and to the external scrotal layer, on the other, assists the scrotal ligament (page 2042) in preventing the testicle from being floated up when the space between the two layers of the tunica vaginalis is filled with fluid (hydrocele, hæmatocele), and holds it in the lower back part of the scrotum.

In exploratory puncture, or in the tapping of hydrocele, the spot selected is therefore on the anterior surface of the upper two-thirds of the scrotum, care being taken to avoid the large superficial veins.

THE PENIS.

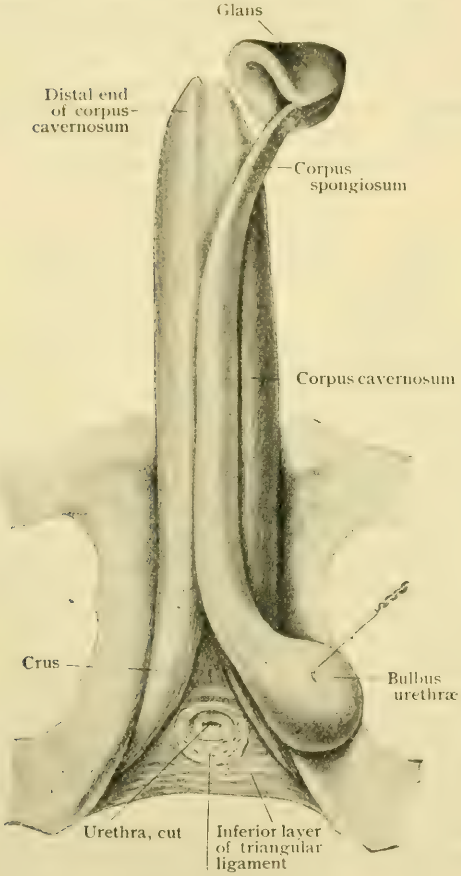
The penis, the organ of copulation of the male, consists of three cylinders of erectile tissue—the paired corpora cavernosa and the single corpus spongiosum—united with one another and invested by coverings of fascia and skin. Since the upper or proximal portion of the penis (**pars perinealis**) is buried beneath the integument and fascia of the perineum and the scrotum, only the free pendulous distal portion of the organ is visible in the undissected subject.

When exposed throughout its entire extent, the penis presents a cylindrical shaft or *body* (**corpus penis**), which begins above in a three-pronged *root* (**radix penis**) attached to the pubic arch and the triangular ligament and terminates below in a blunted conical end, the *glans penis*. The anterior or upper surface (**dorsum penis**) is somewhat flattened and formed by the corpora cavernosa. The posterior, under, or urethral surface (**facies urethralis**) corresponds to the corpus spongiosum, traversed

by the urethra, and is marked by a median raphe, which is continuous with that of the scrotum and, as the latter, indicates the line of fusion of the original components of the spongy body.

The conical *glans*, which forms the distal end of the organ, is limited along its oblique base by a prominent rounded border, the *corona glandis*, that runs downward and forward from the dorsum towards the under surface and marks a groove (**sulcus retroglandularis**) that separates the glans from the body of the penis. The constricted zone immediately behind the glans constitutes the *neck* (**collum penis**). In consequence of the obliquity of the corona, the dorsal expansion of the glans measures about twice the length of its under surface.

Fig. 1673.



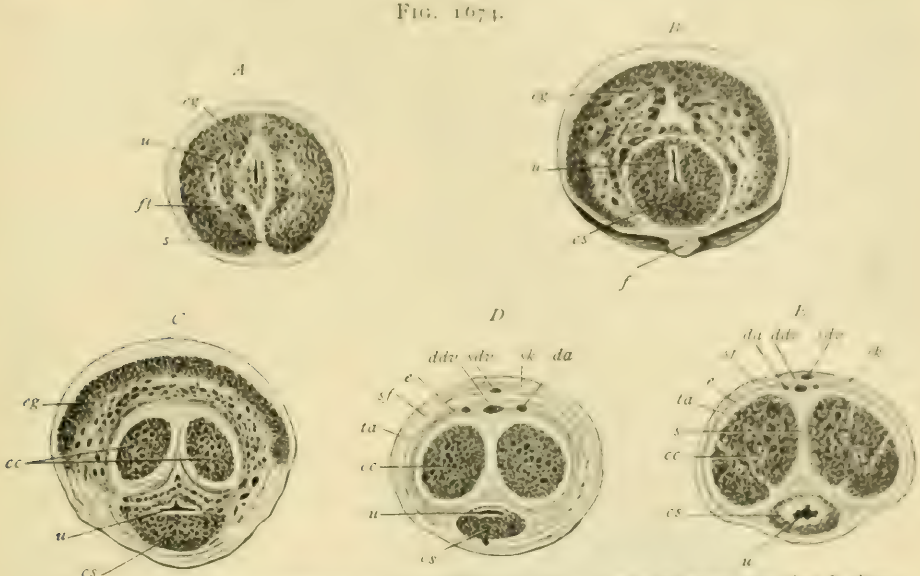
Dissection of penis, showing three component cylinders of erectile tissue; distal end of corpus spongiosum, with glans, has been freed and turned aside; attachment of urethral bulb has been cut and bulb drawn aside.

The *skin* covering the pendulous portion of the penis—very thin, delicate, and elastic, and possessing only fine hair (lanugo) except in the immediate vicinity of the pubes—is loosely attached over the body of the organ by subcutaneous tissue, devoid of fat, that permits of ready movement of the integument. Along the under surface of the organ bundles of involuntary muscle closely adhere to the integument and constitute a stratum, the *tunica dartos penis*, that resembles the similar layer of the scrotum. Just behind the corona the skin forms a free duplicature, the *prepuce* or *foreskin* (**praeputium penis**), that covers the glans to a variable extent (in children and in some adults completely) and is firmly attached by its inner layer to the neck of the penis along a line about 3 mm. above the corona. From this point the skin is prolonged over the glans, to which it is intimately applied, as far as the meatus, where the integument becomes continuous with the urethral mucous membrane. The lines of reflection of the prepuce on the two sides converge and finally meet along the under surface of the glans in a sharp median fold, the *frenum* (**frenulum praeputii**), that extends as far as the posterior border of the slit-like urethral opening. On either side of this fold a shallow recess (**fossa frenuli**) extends the preputial sac. The skin lining the latter and covering the glans is modified so that it somewhat resembles a mucous membrane, as which it is often inaccurately described. While entirely devoid of hairs, small sebaceous glands are sparingly distributed over the glans, corona, and inner layer of the prepuce. These, formerly supposed to be of large size and named the *glands of Tyson* (**glandulae praeputiales**), secrete unctuous material which, mixed with discarded epithelial cells, may collect in the groove behind the corona as a cheesy substance, the *smegma*.

The **corpora cavernosa** (**corpora cavernosa penis**) are two cylinders of erectile tissue, when relaxed about 15 cm. (6 in.) in length, that form the chief bulk of the body of the penis. Each is enclosed within a dense fibro-elastic envelope, or *tunica albuginea*, which internally is continuous with the trabeculæ between the blood-spaces. Beginning above at the root of the penis as the diverging pointed and then

somewhat expanded *crura* attached to the inner border of the pubic arch, the cavernous bodies are at first separated by an interval occupied by the bulb of the corpus

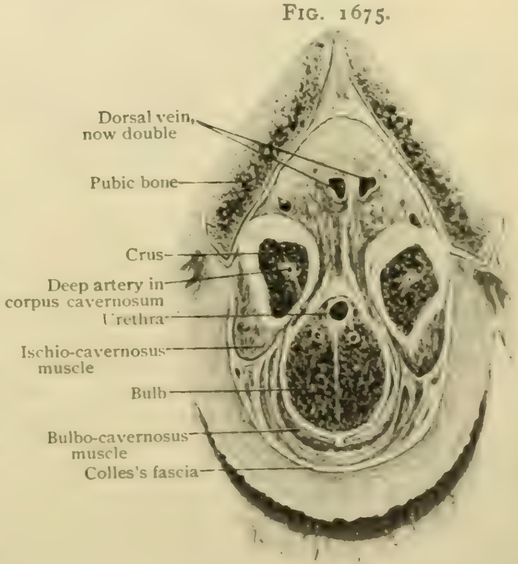
FIG. 1674.



Cross-sections of formalin-hardened penis at different levels. *A*, through glans, near tip; *B*, about middle of glans; *C*, through corona; *D*, body, distal part; *E*, body, proximal part. *cc*, corpus cavernosum; *cs*, corpus spongiosum; *da*, dorsal artery; *ddv*, deep dorsal vein; *e*, fibrous envelope; *cg*, erectile tissue of glans; *f*, frenum; *ft*, fibrous tissue; *s*, fibrous septum; *sdv*, superficial dorsal vein; *sf*, superficial fascia; *sk*, skin; *ta*, tunica albuginea; *u*, urethra.

spongiosum. Farther forward, in the vicinity of the penile angle, the corpora cavernosa press against each other with their median surfaces, the opposed flattened capsules blending to form a median partition (**septum penis**). Lower the latter becomes imperfect and replaced by a series of vertical bands, and hence is often designated the *pectiniform septum*, the intervening slit-like apertures permitting communication between the blood-spaces of the two cavernous bodies, as well as the passage of anastomotic branches of their arteries. In certain mammals, especially the carnivora and some marsupials, a bone (os penis) is developed within the fibrous septum. On approaching the corona, the corpora cavernosa again become discrete and rapidly taper to blunt-pointed ends that are separated externally by a slight furrow and capped by the overlying glans. The dorsal and under surfaces common to the closely applied cavernous bodies are marked by longitudinal grooves; that along the former surface lodges the dorsal vessels of the penis, while the under furrow is filled by the spongy body.

FIG. 1675.



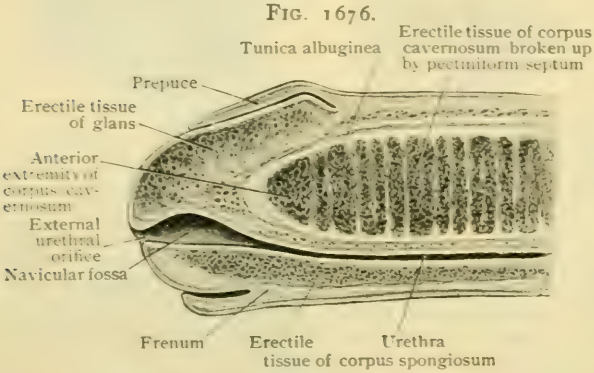
Frontal section through pubic arch and root of penis.

The **corpus spongiosum** (**corpus cavernosum urethrae**), the third and much smaller, although longer (about 17 cm. or 6¾ in.), cylinder of erectile tissue, occupies the groove along the under surface of the cavernous bodies. The two ends of this cylinder are enlarged, the

upper expanding into a pyriform mass of erectile tissue, the *urethral bulb* (**bulbus urethrae**), and the lower broadening into a conical cap of erectile tissue that covers the ends of the corpora cavernosa and contributes the bulk of the glans. With the exception of the bulb, the major part of which lies behind the canal, the corpus spongiosum is traversed by the urethra, the cavernous tissue completely surrounding the urinary tube. The bulb, attached by its upper surface to the inferior layer of the triangular ligament and covered below by the bulbo-cavernosus muscle, presents a slight median furrow (**sulcus bulbi**) that suggests a division into the so-called *hemispheres*. Internally an imperfect median *septum bulbi* partially subdivides the erectile tissue below and behind.

The **glans penis** consists almost entirely of erectile tissue (**corpus cavernosum glandis**) directly continuous with that of the spongy body. Its upper surface is hollowed out to receive the pointed extremities of the corpora cavernosa, so that a section across the upper part of the glans shows the erectile tissue of the cavernous bodies surrounded by an overhanging crescent of the cavernous tissue of the glans (Fig. 1674, *C*). Along the frenum the fibrous envelope of the glans is prolonged inward towards the urethra as a fibro-elastic band (**ligamentum medianum glandis**) which, in conjunction with a similar band connecting the ends of the cavernous bodies with the upper urethral wall, forms a median partition, the *septum glandis*, that incompletely divides the erectile tissue of the glans and surrounds the terminal part of the urethra.

FIG. 1676.



Mesial longitudinal section of end of penis.

The penile portion of the urethra is described with the other parts of the urinary tract in the male (page 1923).

Beneath the skin and subcutaneous tissue the cylinders of erectile tissue, enclosed and united by their albuginea, are enveloped by the superficial fascia (Fig. 1674, *E*). The latter, directly continuous with that of the perineum (Colles fascia) behind and of the abdomen (Scarpa's fascia) above, invests the penis as far as the neck, where it becomes blended with the prepuce. This fibro-elastic sheath is often called the *fascia penis*.

In addition to the attachment of the crura of the corpora cavernosa to the periosteum of the pubic arch and of the bulb of the spongy body to the triangular ligament, the penis is supported by fibrous bands that extend from the abdominal wall and pubes to the dorsum penis. This triangular sheet, the *suspensory ligament*, includes a superficial and a deeper portion. The former (**ligamentum fundiforme penis**) begins at the linea alba, from 4–5 cm. (1½–2 in.) above the symphysis, and consists of elastic bundles prolonged from the deep layer of the superficial fascia downward to the dorsum of the penis (Fig. 1671) at the so-called angle, where it divides into two arms that embrace the penis and, after uniting on the urethral surface, are continued into the septum scroti. The deeper portion (**ligamentum suspensorium penis**) contains compact fibrous bands that pass from the symphysis to the corpora cavernosa, just in advance of their separation into the diverging crura, to blend with the dense albuginea.

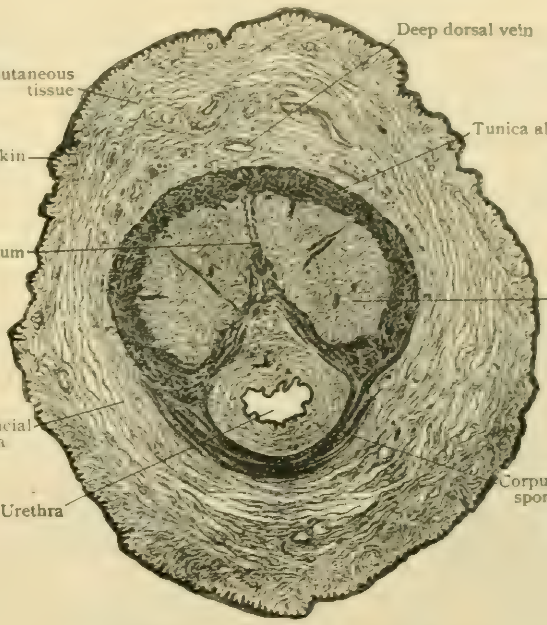
Structure.—Each of the component cylinders of erectile tissue is enclosed in a robust sheath, the *tunica albuginea*, composed of dense white fibrous tissue, intermingled with relatively few elastic fibres and no muscle. The sheath surrounding the corpora cavernosa, which in places attains a thickness of 2 mm. and is much stronger than that enclosing the spongy body, is imperfect along the opposed median surfaces of the two cylinders, where it forms the pectiniform septum.

From the inner surface of the tunica albuginea septa and trabeculæ are given off which constitute the framework supporting the vessels and nerves and enclosing the characteristic blood-spaces of the erectile tissue. Numerous bundles of *involuntary*

muscle, circularly, longitudinally, and obliquely disposed, occupy the connective-tissue trabeculæ and plates separating the venous lacunæ, around which they form imperfect layers of contractile tissue. The trabecular muscle is most developed within the cavernous and spongy bodies and least so within the glans.

The arteries conveying blood to the cylinders of erectile tissue are of two kinds, —those nourishing the tissues themselves (*vasa nutritia*) and those carrying blood to the venous lacunæ. The latter are connected with the arteries either directly by minute channels or through intervening capillaries. Within the trabeculæ of the deeper parts of the erectile masses the deep arteries of the penis give off short, tortuous branches (*arteriæ helicinæ*), about 2 mm. in length, that project into the blood-spaces with which they directly communicate by minute openings at their ends. Notwithstanding their exceptional development in man, the fact that the helicine arteries are wanting in many mammals shows that they are not essential, although advantageous, for erection. The arteries of the erectile tissue are distinguished by the unusual thickness of the circular muscle within their walls. In places the intima likewise exhibits excessive thickness. Since the increase is not uniform but local, it leads to the production of cushion-like elevations that encroach upon and even temporarily occlude the lumen of the arteries.

Fig. 1677.



Transverse section of penis of child. × 10.

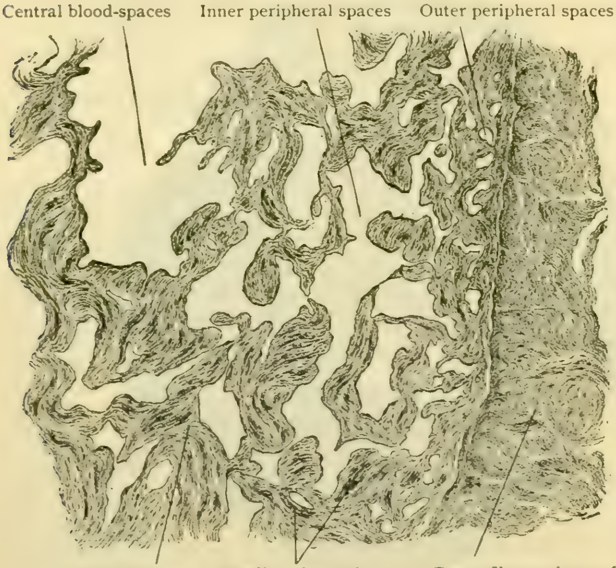
The *blood-spaces* or *lacunæ* that occupy the interstices between the trabeculæ are to be regarded as venous net-works which communicate with the arteries, on the one hand, and with the radicles forming the veins, on the other. Their form and size evidently depend upon the degree of distention, when containing little blood the spaces being often mere slits or irregularly stellate clefts, while when filled they become more cylindrical in form. In a general way three districts may be distinguished: (*a*) a narrow *outer peripheral zone* of almost capillary spaces, for the most part narrow and triangular in outline; (*b*) an *inner peripheral zone* of larger spaces of uncertain form and from .15–.20 mm. in diameter; and (*c*) a *central zone* of still more extensive spaces, which in places attain a diameter of one or more millimetres and are enclosed by relatively thin intervening lamellæ and trabeculae. Since their expansion is usually greater in one direction, the general form of the larger and deeper lacunæ is often approximately cylindrical. Within the corpus spongiosum in the immediate vicinity of the urethra the blood-spaces are somewhat concentrically disposed owing to the feeble development of the radial lamellæ (Eberth). The spongy body is further distinguished by the robustness of its trabeculæ and the consequent reduction in the size of the blood-spaces. Beyond the single layer of endothelial plates, the lacunæ do not possess a distinct wall other than the fibro-muscular tissue of the surrounding trabeculæ.

The deep veins draining the cylinders of erectile tissue do not directly open into the blood-spaces, but are formed by tributaries of various size that begin as apertures in the walls of the lacunæ, of which they are in fact extensions. The tributaries of the

more superficially situated venous trunks, as the dorsal vein, arise chiefly from the venous net-works of the peripheral zone. The veins possess an unusually well-developed muscular coat, and in places exhibit local cushion-like thickenings of their intima similar to but less markèd than those seen in the arteries.

Vessels.—The *arteries* of the penis constitute a superficial and a deep set, the former supplying the integument and associated envelopes, while the latter convey blood to the masses of erectile tissue. The *superficial arteries* include twigs from the external pudic branches of the femorals to the lateral and under surface of the penis, from the dorsal arteries to the anterior surface and the prepuce, and from the superficial perineals by small vessels to the posterior part of the urethral surface. The *deep arteries*—all branches from the internal pudics—supply the three cylinders of erectile tissue, including the glans. The corpus spongiosum receives the arteries of the bulb, their continuations (sometimes described as the urethral arteries) accompanying the urinary canal as far as the glans, where they anastomose with the terminal branches of the dorsal arteries. The last-named vessels also send small twigs around the corpora cavernosa to the spongy body. The corpora cavernosa are supplied chiefly by the deep arteries of the penis, supplemented by twigs from the dorsal arteries that pierce the albuginea. Entering the cavernous bodies about where the crura unite, the deep arteries of the penis traverse the cylinders somewhat eccentrically, to the median side of their axes. Communication between the vessels of the two bodies is established by anastomotic twigs that pass through the apertures in the median septum, as well as by the terminal loop. The dorsal arteries, the longest branches of the internal pudics, pass along the dorsum between the fascia and the albuginea, in company with the dorsal nerves and vein, and, in addition to the twigs distributed to the coverings, the cavernous bodies, and the corpus spongiosum, supply the erectile tissue of the glans. The anastomoses between the various vessels supplying the penis are very free, not only between the corresponding and other branches of the two sides, but also between those of the superficial and deep sets.

FIG. 1678.



Transverse section through periphery of corpus cavernosum. × 50.

The *veins* of the penis, like the arteries, constitute a superficial and a deep group which freely communicate and carry off the blood from the envelopes and from the erectile tissue respectively. The *superficial veins* for the most part are tributary to a subcutaneous trunk (**v. dorsalis penis superficialis**) that passes upward along the dorsum beneath the skin to the pubes and terminates either by dividing into branches that empty into the internal saphenous or the femoral veins on either side or by joining the deep dorsal vein ; both modes of ending, however, may exist. A number of vessels from the integument covering the posterior part of the urethral surface are collected by the anterior scrotal veins.

The *deep veins*, which begin by tributaries from the erectile tissue that they drain, to a large extent discharge their contents into the deep dorsal vein (**v. dorsalis penis profunda**) that lies beneath the fascia and occupies the groove on the dorsum as far as the suspensory ligament, between the superficial and deep parts of which it

passes. Continuing between the subpubic and transverse ligaments and piercing the fascia, it gains the pelvis and ends, after dividing into two trunks, in the prostatic plexus. Beginning above the corona by the union of two stems that collect branches from the glans and the prepuce, the deep dorsal vein, as it courses upward, receives tributaries from all three cylinders of erectile tissue. Those from the corpora cavernosa either pierce the albuginea as short branches that pass directly into the dorsal vein, or emerge from their under surface along the urethral groove and wind around the body of the penis to reach the collecting trunk on the dorsum, the anterior of these *circumflex veins* taking up tributaries from the under surface of the glans. Within the posterior part of the cavernous bodies are formed the deep veins of the penis, which emerge where the crura diverge and, after establishing communications with the prostatic plexus, become important tributaries of the internal pudic veins that accompany the corresponding arteries. The corpus spongiosum is drained by anterior branches that convey the blood to the dorsal vein by joining the circumflex or other veins from the corpora cavernosa, and by posterior stems (vv. urethrales) that pass upward and backward and empty partly into the prostatic plexus and partly into the internal pudic veins, the veins from the urethral bulb having a similar destination. Numerous anastomoses between the cutaneous veins and those from the erectile tissue establish free communication between the superficial and deep vessels.

The *lymphatics* are numerous and disposed as superficial and deep vessels. The former are tributary chiefly to a superficial dorsal stem that accompanies the corresponding vein and begins by the confluence of plexiform lymphatics within the integument of the prepuce and frenum. During its course the dorsal trunk receives lymphatics from the adjacent territory as well as others from the under surface that gain the dorsum by following the circumflex veins around the body of the penis. At the pubes the superficial dorsal lymph-trunk passes either to the right or left, or, when double, as it occasionally is, to both or even opposite sides, and joins the median group of superficial inguinal lymph-nodes. Direct communications with the deep subinguinal nodes sometimes exist (Küttner). The deeper lymphatics are particularly numerous in the periphery of the glans, around the meatus communicating with the urethral and preputial plexuses. Trunks are formed which occupy the retroglandular sulcus and unite into a deep dorsal lymph-stem, sometimes double, that accompanies the corresponding vein beneath the fascia and terminates, when single, in the median inguinal nodes of the left side (Marchant).

The **nerves** of the penis include both spinal and sympathetic fibres, the former from the ilio-inguinal and the pudic nerves, and the latter from the hypogastric plexus. The integument around the root of the penis is supplied by the cutaneous branches of the ilio-inguinal and the inferior pudendal nerves, while that of the body and the prepuce is provided with the cutaneous branches of the dorsal nerves. The cylinders of cavernous tissue also receive twigs from the pudic nerves, the bulbar branches of which pass to the bulbus urethræ and in addition supply the mucous membrane of the urethra. Each corpus cavernosum receives a deep branch from the dorsal nerve which is given off as the latter lies between the layers of the triangular ligament. The sympathetic fibres destined for the blood-vessels and muscle of the erectile tissue are continued from the hypogastric plexus through the prostatic plexus to the plexus cavernosus, where, joining the dorsal nerves of the penis, twigs (**nervi cavernosi penis minores**) are sent to the posterior part and the crura of the corpora cavernosa, while others (**nervi cavernosi penis majores**) are distributed to the lower portions of the erectile masses, some fibres terminating within the spongy body. Close net-works of non-medullated fibres have been traced within the bundles of involuntary muscle of the blood-vessels and trabeculæ of the erectile tissue. Certain cerebro-spinal fibres (**nervi erigentes**) supposed to be especially concerned in erection are conveyed, in company with the sympathetic fibres, along the paths of the cavernous plexus.

In addition to a generous supply of the more usual nerve-terminations, the skin of the glans and the prepuce is provided with special nerve-endings,—the tactile bodies and the genital corpuscles of Krause (page 1017) lying within the papillæ and the Pacinian corpuscles within the subcutaneous stratum. The paths of the sensory impressions lie within the dorsal nerves.

Variations.—Apart from the unimportant individual differences due to age, growth, and sexual activity, the variations of the penis are for the most part referable to imperfect development and are recognized as malformations rather than as anatomical deviations. The explanation of many of these conditions is supplied by the developmental history of the structures involved (page 2044).

PRACTICAL CONSIDERATIONS: THE PENIS.

The size of the penis bears less constant relation to general physical development than does any other organ of the body. The normal average size of the flaccid penis of the adult is about three inches in circumference and from three and a half to four inches in length, measured from the suspensory ligament. When erect, this length increases to about six and a half inches and the circumference to three and a half or more.

Absence of the penis may occur, but is rare unassociated with other anomalies. Apparent absence (concealed penis) may be due to the subcutaneous situation of an atrophic or undeveloped organ which may be palpated through the skin and revealed by an incision.

Micropenis (infantile penis) is not uncommon, and varies in degree from a mere failure to attain quite the average size (annoying chiefly to sexual neurasthenics) to a retention throughout life of the dimensions and development normal in early childhood or infancy. Occasionally in such cases, after puberty and following physiological activity of the organ, rapid growth takes place and conditions approximating normality may result.

Megalopenis.—As has already been observed, the size of the organ bears no constant relation to the size or strength of the individual. In congenital imbeciles it is often of unusual size, and in dwarfs and hunchbacks it is not uncommonly developed, not only out of proportion to the other parts of the organism, but beyond even the average for individuals of normal growth. Hypertrophy of the penis is at times an inconvenience, and may even be a source of danger, since an excessive development predisposes to abrasions and fissures through which inoculation with venereal diseases may occur.

Double penis has been recorded in a few instances, in at least two of which each organ was functionally perfect.

The *skin* of the penis is thin and delicate (to maintain the sensitiveness of the organ), and is lax and elastic (to permit of its changes in size). On account of these qualities abrasions are not unusual, and through them syphilitic infection frequently takes place.

The loose, plentiful layer of subcutaneous connective tissue permits of enormous œdematous swelling as a result of ordinary staphylococcic or streptococcic (pyogenic or erysipelatous) infection; its abundance in conjunction with the elasticity of the skin, accounts for the disappearance of the penis in cases of very large scrotal hernia, in hydroceles of similar size, and in elephantiasis scroti.

Anterior to the corona the skin is modified and resembles a mucous membrane, at the meatus becoming continuous with the mucosa of the urethra. The line of demarcation between the ordinary and modified cutaneous surfaces is not, however, so distinct as on the lips or the nostrils, the passage of one surface into the other more closely resembling that which takes place at the margin of the anus. On the proximal face of the corona the subcutaneous tissue is still abundant. Over the glans it practically disappears and the modified integument closely embraces the erectile tissue of the expanded anterior extremity of the corpus spongiosum.

Chancres anterior to the corona (except at the frenum) are apt to exhibit the variety of induration known as "laminated" or "parchment-like," corresponding to a sclerosis limited to the papillary layer of the derma and to the vascular net-work of the papillæ. At the frenum, corona, or cervix, where the cellular tissue is abundant, "nodular" induration—a sclerosis of the whole thickness of the derma, of the subdermoid areolar tissue, and of the associated vascular net-work, which is much larger than the superficial or papillary supply—is apt to occur, and is, as the name indicates, deeper, thicker, and harder. On the skin of the penis chancres are apt to be extensive in area, but are limited in depth by the firm, resistant fascia penis.

At birth the *prepuce* is normally adherent to the glans, its moderate retraction barely exposing the meatus. Continued retraction everts the lips of the meatus and then separates the epithelial adhesions between glans and prepuce, ultimately exposing a congested surface and causing punctate hemorrhages.

This separation should normally take place during infancy or early childhood, either spontaneously as a result of erections and of the growth of the organ or because of gradual mechanical retraction by nurse or mother. When it fails to do this, the condition of *phimosis* —inability to retract the prepuce—follows, and is due partly to the persistent adhesions and partly to a frequently associated narrowing of the preputial orifice.

Both these factors may be the result of disease, and acquired phimosis may occur at any time of life and follow any form of inflammation of the skin covering the glans (*balanitis*), of the inner surface and cellular tissue of the prepuce (*posthitis*), or of both (*balano-posthitis*), the last named being the most common. Following phimosis there may be, (*a*) as a result of retention of secretion and of urine in the subpreputial space, balanitic or herpetic ulceration, or the development of papillomata (venereal warts); (*b*) as a result of obstruction to the flow of urine and the consequent straining, vesical irritability, dilatation of the bladder, ureters, and kidneys, hemorrhoids, and hernia (62 per cent. of cases of congenital phimosis) (Kempe, quoted by Jacobson); (*c*) as a result of nerve irritation (the region having an unusually rich nerve-supply), spastic palsies, reflex joint pains and muscular spasm (simulated coxalgia), or even general convulsions.

These complications are most apt to occur in infants and very young children, and their frequency has been exaggerated.

As a result of phimosis, even when the preputial orifice is ample, there may be a contracted or "pin-point" meatus, which may give rise to the same train of symptoms and will require to be divided (*meatotomy*) by a linear incision directed towards the frenum, and kept open during the process of healing.

Circumcision, whether done for phimosis or to meet other indications, requires for its successful performance attention to the following anatomical points: (*a*) the laxity of the skin, permitting it easily to be drawn so far in front of the glans that when it is severed at that point so much may be removed that the remainder retracts quite to the root of the organ, which is left denuded; (*b*) the close attachment of the inner or mucous layer of the prepuce to the corona, so that the length of the portion of that layer that is allowed to remain will determine the distance of the operative scar (at the muco-cutaneous junction) from the meatus; if this stump is not excessive, it will thus effectually prevent the mortifying but not infrequent accident of re-formation of a phimosis after a circumcision; (*c*) the loose, abundant cellular tissue and rich vascular supply in the frenal region, which, together with the dependent position of the part, may determine an excess of exudate that will result in an objectionable fibrous mass in that region if full hæmostasis is not secured or if any redundant tissue is left there.

When a relatively small preputial orifice is drawn behind the corona it causes marked constriction at that point, especially if it is not only small but also inelastic as a result of chronic inflammation. If the constriction remains unrelieved, *paraphimosis* results; the glans becomes distinctly enlarged, increasing the constriction, purplish in color, and glossy. It is often partially concealed by a thick collar of shiny, œdematous skin, behind which there is a deep, excoriated sulcus, and back of this sulcus there is usually a second œdematous band less marked than the one lying immediately behind the coronary sulcus. The penis seems to have a distinct upward kink or bend just behind the glans. This appearance is due to the deep notch caused by the margin of the retroverted orifice of the prepuce and to the œdematous swelling which is particularly marked about the position of the frenum. In some cases, where the tense, inelastic edge of the orifice exerts a more than usual amount of constriction, circulation is markedly interfered with, and ulceration and even sloughing involving both the foreskin and the head of the penis may take place. This complication would undoubtedly be more frequent were it not for the rich blood-supply to the glans and the anastomosis between its vessels and those of the corpora cavernosa. The ulceration usually involves the foreskin only.

When the swelling consequent upon paraphimosis is well developed there is encountered first a furrow, the coronary sulcus, which is normally found behind the corona; in these cases it appears deeper because it is intensified by the œdematous swelling. Covering this furrow, and even overlapping the glans somewhat, is the portion of the prepuce which is normally in contact with the posterior face and border of the corona. Behind this swollen fold is found a second deep, often ulcerated furrow indicating the position of the preputial muco-cutaneous margin; this is the actual seat of constriction, and behind it is placed yet another ridge of swollen integument.

The *fascia penis* (page 1968) gives the organ some of its most important physical characteristics. The tensile strength of the penis, because of its tough fibrous investments, is sufficient to bear the entire weight of the body. That portion of this fibrous investment which covers the blunt extremities of the two cavernous bodies where they are capped by the glans, delays, and sometimes prevents, the backward extension of inflammatory or infiltrating processes, particularly cancerous infiltration, which primarily involve the glans. This fibrous sheath, being a continuation of the deep layer of the superficial fascia, also limits the forward extension of urinary and purulent infiltrations beneath this fascia, such infiltrations leaving the glans uninvolved. The free blood-supply to the penis and its rich innervation insure rapid healing in case of wounds, and justify conservative treatment even although the organ has been nearly severed or extensively crushed.

Contusion of the penis is often followed—owing to the laxity of the skin—by such rapid and pronounced ecchymosis and œdema as to simulate gangrene.

When the vessels of the cavernous bodies are involved there is free subcutaneous bleeding, giving rise to a circumscribed fluctuating tumor, most prominent during erection. This tumor is somewhat slow in forming, and occasionally suppurates. Under conservative treatment it usually disappears. When injury has not only occasioned extensive extravasation of blood, but has lacerated the urethral canal, the inflammatory phenomena observed after rupture of the urethra quickly develop. Moreover, there is immediately bleeding from the meatus, which should lead to prompt diagnosis and appropriate treatment.

Wounds, if involving the erectile tissue, bleed freely, and, if transverse and extensive, may be followed by loss of erectile power in the region anterior to the wound.

Fracture, in a literal sense, is possible only when the organ has undergone calcification or ossification (*vide infra*), but the term is applied to injuries that result when, during vigorous erection, the penis is subjected to a sudden twist or bend. The resulting condition is not unlike that caused by contusion, but the subcutaneous effusion is apt to be lacking. The chief lesion is usually in the corpora cavernosa, or in one of them, and is apt, as a result of obliteration of erectile spaces, to leave a flail-like organ, erection anterior to the break being impossible.

Chronic induration (ossification, calcification, chronic inflammation) of the sheath and erectile tissue, especially of the corpora cavernosa, is marked by the formation of fibrous, calcareous, or bony thickenings or plates, which form usually in middle-aged or elderly men of gouty diathesis. They cause but little pain, are easily recognized by palpation, and are accompanied by bending of the penis to the affected side during erection, which is incomplete in the region anterior to the induration. The condition is unknown before forty or forty-five, and is probably analogous to the thickening and toughening of the palmar fascia, which goes by the name of Dupuytren's contraction, and which we recognize as partly due to gout and partly to some constant irritation. Thus they may be met with in both the penis and the hands of the same gouty person (Jacobson). It has been suggested (Metchnikoff) that in their osseous form they represent reversions to the condition existing in many mammals and even in the anthropoid apes, in whom an *os penis* is present.

Lymphangitis may follow peripheral inflammation of any type, but is usually of venereal origin.

The diagnosis between lymphangitis and phlebitis of the dorsal vein is based upon the much smaller size of the lymphatic vessels as compared with the vein; upon the fact that the former vessels do not pass upward in the middle line, but are directed into the groins; and finally upon the ability to lift the indurated vessel up from the deeper parts, this not being possible in the case of the vein, since it is placed in a

furrow between the two cavernous bodies. Phlebitis occasions much more marked œdema.

Epithelioma of the penis is not uncommon. It usually follows prolonged subpreputial irritation. It involves ultimately both the inguinal and the deep pelvic nodes.

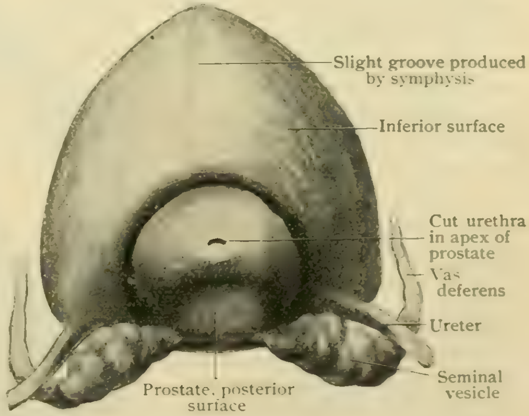
Amputation of the entire penis may be required for the relief of malignant disease. The following description (Treves) should be studied in connection with the anatomy of the penis and of the urethra. The patient is placed in the lithotomy position, and the skin of the scrotum is incised along the whole length of the raphe. With the finger and the handle of the scalpel the halves of the scrotum are separated down to the corpus spongiosum. A full-sized metal catheter is passed as far as the triangular ligament, and a knife is inserted transversely between the corpora cavernosa and the corpus spongiosum. The catheter is withdrawn, the urethra is cut across, and its deep end is detached from the penis back to the triangular ligament. An incision is made around the root of the penis continuous with that in the median line. The suspensory ligament is divided and the penis is separated, except at the attachment to the crus. The knife is then laid aside, and with a stout periosteal elevator or rugine each crus is detached from the pubic arch. The two arteries of the corpora cavernosa and the two dorsal arteries require ligature. The urethra and corpus spongiosum are split up for about half an inch, and the edges of the cut are stitched to the back part of the incision in the scrotum. The scrotal incision is closed by sutures, and if drainage is used, the tube is so placed in the deep part of the wound that its end can be brought out in front and behind. No catheter is retained in the urethra.

THE PROSTATE GLAND.

Although developed as an appendage of the urinary tract, and not directly as part of the sexual apparatus, the prostate is functionally so closely related to the generative organs that it may appropriately be regarded as one of the accessory glands, the others being the glands of Cowper.

The prostate is complex in both its make-up and relations, being partly glandular and partly muscular and traversed by the urethra and the ejaculatory ducts. In general form it resembles an inverted Spanish chestnut, having the base applied to the under surface of the bladder and the small end, or *apex*, directed downward. Additional anterior, lateral, and posterior surfaces are recognized. Grayish red in color and of firm consistence, the adult prostate varies considerably within physiological limits in size and weight. The former includes a length, from apex to base, of from 2.5–3.5 cm. (1 to 1 3/8 in.), a breadth or transverse diameter of from 3.5–4.5 cm. (1 3/8–1 3/4 in.), and a thickness of from 2–2.5 cm. (4/5–1 in.). Its average weight is about 22 gm. (3/4 oz.). Marked increase in size and weight is common in elderly subjects.

FIG. 1679.

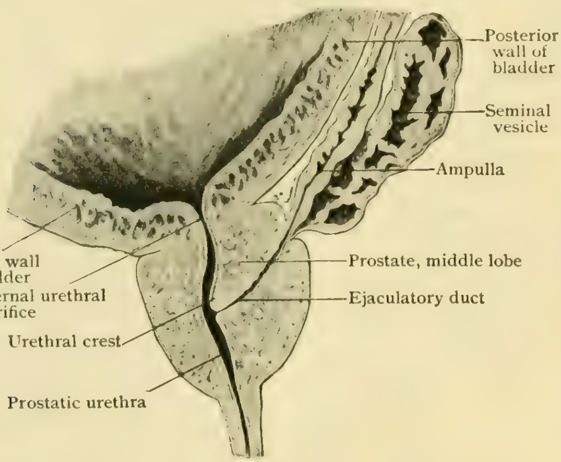


Slightly distended bladder, hardened *in situ*, showing prostate, seminal vesicles, and seminal ducts; viewed from below and behind.

The oblique *upper surface* or *base* (**basis prostatae, facies vesicalis**) is applied to the under surface of the bladder, with which it is inseparably blended by muscular tissue surrounding the urethral orifice, and is pierced by the urethra usually slightly in advance of the middle. The base is outlined by free rounded borders, so that its limits are separated from the vesical wall by a groove. The *posterior surface* (**facies posterior**), directed backward and towards the rectum, is defined laterally by prominent rounded borders that extend from the base to the apex and enclose a flattened cordiform or triangular area

that often presents a shallow concavity. The junction of the upper and posterior surfaces is marked by a transverse crescentic slit (**incisura prostatae**) into which sink the ejaculatory ducts in their course to the urethra. The imperfectly defined wedge-shaped mass bounded by the urethra in front, the ejaculatory ducts at the sides and behind, constitutes the so-called *middle lobe* (**lobus medius**), the base of which lies beneath the vesical trigone. The prominent portions of the prostate lying external to the ejaculatory ducts are known as the lateral lobes, which, however, superficially are not distinctly marked off. The prominent convex *lateral surfaces*, directed outward, downward, and forward, and behind limited by rounded borders, in front pass insensibly into the narrow convex *anterior surface* (**facies anterior**) that is approximately vertical and faces the symphysis.

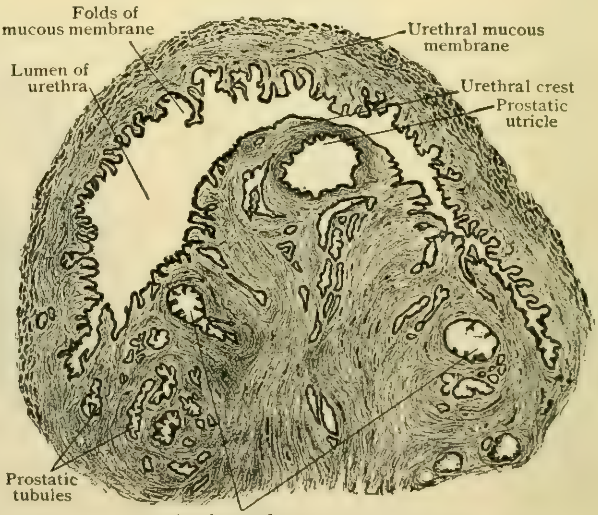
FIG. 1680.



Portion of sagittal section showing prostate and related structures.

The urethra traverses the prostate with a vertically placed curve, the concavity looking forward, that above begins slightly in advance of the middle of the base, and below ends on the anterior surface just in front and above the apex. The posterior wall of the prostatic urethra is marked by a longitudinal median ridge, the *urethral crest*, on the most expanded and elevated part of which (**colliculus seminalis**) are situated the openings of the *prostatic utricle* (**utriculus prostaticus**) and of the ejaculatory ducts (page 1955). In the grooves or *recesses* on either side of the crest, open the minute orifices of the prostatic tubules, some twenty in number, that discharge the products of the glandular tissue.

FIG. 1681.



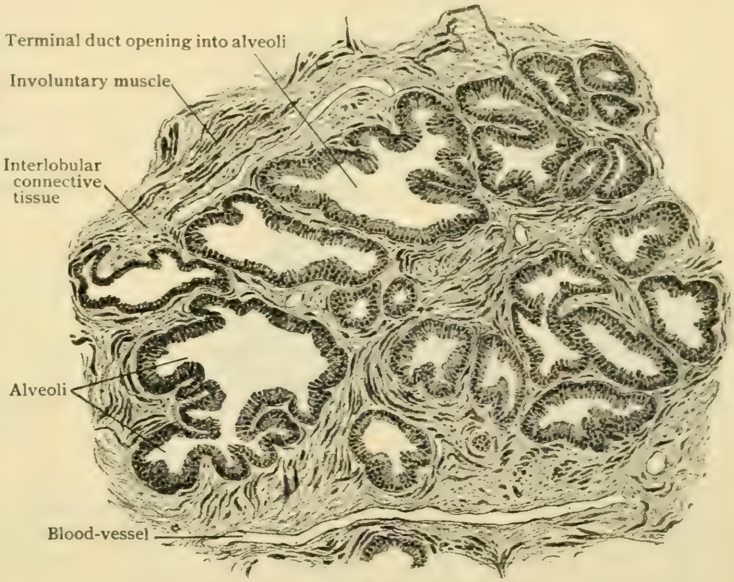
Section across prostatic urethra above entrance of ejaculatory ducts, showing crescentic form of urethral lumen produced by encroachment of urethral crest. × 10.

Owing to the continuity of the muscular tissue with the surrounding structures in front, above, and below, the outlines of the prostate in places lack definition. Except over its base, apex, and lower anterior surface, the prostate is enclosed by a fibrous envelope or *capsule*, the extension of the visceral layer of the pelvic fascia in conjunction with the investment of the bladder and the seminal vesicles. The capsule is best developed on the posterior surface, where it separates the prostate from the rectum and constitutes a part of the recto-vesical fascia in its restricted sense.

Relations.—Lodged between the bladder and the pelvic floor, the prostate is in relation with a number of important structures. *Above*, its base is intimately

attached to the lower surface of the bladder, lying beneath the vesical trigone. *Below*, its apex rests upon the superior layer of the triangular ligament, surrounded by fibres of the compressor urethræ muscle that constitute the external vesical sphincter (page 1925). *In front*, the rounded anterior surface is directed towards the pubic symphysis, from which it is separated by an intervening wedge-shaped space occupied by loose areolar tissue containing part of the prostatic plexus of veins and fat. The pubo-prostatic ligaments (the continuations of the arcus tendineus of the two sides) stretch between the symphysis and the prostate and contain muscular tissue prolonged from the latter and the bladder. *At the sides*, the prostate is embraced by the levator ani muscles, the prostatic venous plexuses, embedded within the reflections of the pelvic fascia that here constitute the capsule of the gland, intervening. *Behind*, the prostate is in relation with the ampullæ of the vasa deferentia and the seminal vesicles above and with the lower part of the rectum below, separated from the latter by the dense capsule and the overlying layer of areolar tissue. The position of the prostate is not constant, since it is affected by movements of the vesical wall, with which the prostate is intimately united, incident to marked distention and contraction of the bladder. On the other hand, the attachments of the prostate to the triangular ligament and pelvic fascia indirectly confer upon the lower segment of the bladder its most efficient means of fixation. The prostate is further influenced by changes in the anterior wall of the rectum, undergoing compression and displacement forward when the bowel is distended.

FIG. 1682.



Portion of cross-section of prostate gland. × 75.

Structure.—The prostate is a gland of the tubo-alveolar type and is made up of three chief components,—the connective-tissue framework, involuntary muscle, and the glandular tissue. Of these the latter constitutes usually a little more than one-half of the entire organ, and the connective tissue and muscle each somewhat less than one-quarter.

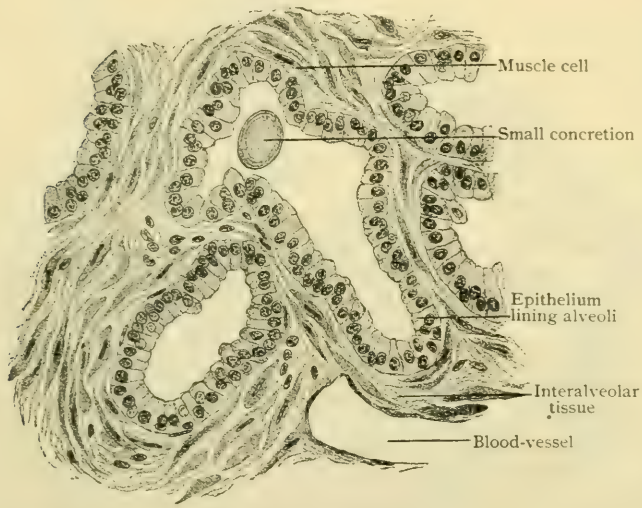
The connective-tissue *framework* consists of an external investing fibro-elastic envelope, the *capsule proper*, and a *median septum*, which encloses and blends with the walls of the urethra. Between these denser lamellæ numerous partitions radiate and subdivide the organ into from thirty to forty pyramidal lobules occupied by the glandular tissue. The *involuntary muscle*, embedded within the capsule and ramifications of the connective-tissue framework, surrounds the gland-substance as a superficial layer from which a median septum, about 2 mm. in width, extends ventro-dorsally, enclosing the urethra in an annular thickening. In consequence, the interior of the prostate is occupied by a dense fibro-muscular *nucleus*, in which the glandular tissue is represented by only the narrow prostatic ducts passing towards the urethra. The muscle is not limited, however, to the foregoing positions, but extends also between the ultimate divisions of the gland-tissue, the interalveolar septa in places consisting largely of the variously disposed muscle-bundles.

The *glandular tissue* consists of twenty or more distinct tube-systems, each drained by an independent duct that opens into the urethra in the groove on either side

of the colliculus. Beginning at their narrow orifices, these excretory tubules (**ductuli prostatici**) pass outward into the lobules, and after a course of about 1 cm. divide into tubules that repeatedly branch and expand into the terminal alveoli. Throughout the greater part of their course the wavy ducts are beset with saccular and tubular diverticula, simple or compound, that give the canal an irregular lumen and constitute what have been termed the *duct alveoli* as distinguished from the *terminal alveoli*. The latter form a series of irregularly branched tubular and saccular spaces lined with a single or imperfect double layer of columnar epithelial cells,—the secreting elements of the gland. In places the alveoli intercommunicate and form net-works of spaces of variable lumen. The epithelium in the ducts and their diverticula corresponds with that lining the more deeply situated alveoli, the change into the transitional variety of the prostatic urethra not taking place until very near the termination of the ducts.

Peculiar *concretions* ("amyloid bodies" or "prostatic calculi") are almost constantly present within some of the tubules of the adult organ, especially in advanced life. These bodies (Fig. 1683), round or oval in outline and very variable in size (from .2–1 mm. and more in diameter), usually exhibit a faint concentric striation and a light brownish color. Their nature is uncertain, but they probably consist of a colloid substance giving protein reactions.

FIG. 1683.



Portion of section of prostate gland, showing details of alveoli. × 270.

The *secretion* of the prostate gland (*succus prostaticus*) is milky in appearance, thin in consistence, slightly alkaline in reaction, and possesses a characteristic odor (Fürbringer). It is discharged into the urethra and mingled with the fluid entering by the seminal ducts during ejaculation, and probably serves an important purpose in facilitating and perhaps stimulating the motility of the spermatozoa. The "sperm crystals" formed in semen after standing, and attributed to the products of the prostate, are not found in the secretion of the living subject (although frequently present in the gland after death) until after the addition of ammonium sulphate (Fürbringer).

Vessels.—The *arteries* supplying the prostate are small branches from the inferior vesical and middle hemorrhoidal. They enter the periphery of the gland at various points, particularly in company with the ejaculatory ducts, and break up into capillary net-works that surround the alveoli. The *veins* are exceedingly numerous, forming close mesh-works within the glandular tissue and around the ducts. They leave the organ on either side and unite into a plexus within the capsule, which, receiving the deep dorsal veins of the penis and communicating with trunks from the bladder, seminal vesicles, and rectum, is continued as the prostatico-vesical plexus, tributary to the internal iliac veins. The *lymphatics* are numerous and form a net-work on the lower and posterior surface of the organ from which on either side pass two trunks, a superior and a lateral. The upper and smaller trunks are afferent to the obturator lymph-nodes of the pelvic wall, and the lateral and larger terminate in the internal iliac nodes (Sappey).

The **nerves** of the prostate are chiefly sympathetic fibres derived from the hypogastric plexus, numerous minute ganglia being included along their course. Peripherally situated Pacinian corpuscles are said to be connected with the sensory fibres (Griffiths).

Development.—At about the third month of fœtal life the wall of the primitive urethra undergoes thickening, leading to the production of an annular mass of mesoblastic tissue that surrounds the lower ends of the Wolffian and Müllerian ducts (later the ejaculatory ducts and the prostatic utricle respectively) and subsequently becomes differentiated largely into unstriped muscle. Into this penetrate solid epithelial outgrowths, from the lining of the urethra, which expand into branched cylinders that give rise to the prostatic glandular tissue. These outgrowths are arranged in three groups (Pallin), a ventral, an upper and a lower dorsal. The ventral group gives rise to the glandular tissue in front of the urethra, which at first is relatively abundant, but soon suffers reduction, and in the adult organ is often almost wanting. The dorsal groups produce the important glands of the median and lateral lobes. For a time the latter are arranged as two separate lobes, but afterward become consolidated by the capsule and broken up by the invasion of the fibro-muscular septa.

At birth the prostate measures about 12 mm. in its transverse dimension and remains small until puberty, when it begins to rapidly enlarge, acquiring its full proportions with the establishment of sexual activity. With the approach of old age, the prostate usually undergoes increase in size,—an augmentation often resulting in pathological conditions.

Variations.—Apart from abnormalities in size, the prostate is subject to few variations. Among the latter have been persistence of the original independence of the lateral lobes, absence of the middle and the presence of a fourth lobe. Variations in the relations and mode of ending of the ejaculatory ducts (fusion into a single canal or termination in the prostatic utricle or by a special canal below the crest) or in the prostatic utricle (absence, enlarged size, or unusual opening) are properly referred to deviations in the development of the generative tract.

PRACTICAL CONSIDERATIONS: THE PROSTATE GLAND.

The prostate gland is a portion of the male generative system. The prostatic utricle, or sinus pocularis, is the homologue of the sinus genitalis in the female,—the uterine and vaginal cavities,—since it represents the persistent part of the fused Müllerian ducts (page 2039). Alhough the prostate and the uterus cannot be regarded as homologous organs, they are similar in structure, and would be strikingly alike if the tubular glands found in the inner walls of the uterus were prolonged into its muscular substance.

During infancy and childhood the prostate is still immature ; at puberty it enlarges coincidently with the enlargement of the testicles. In eunuchs and after castration in man and other animals it is atrophied. The seminal vesicles are in close relation to it and the ejaculatory ducts penetrate it (page 1955). Its size and perfection of structure in animals rise and fall with the breeding season (Hunter, Owen, Griffiths). These facts sufficiently demonstrate the essential relation of the prostate to the generative system. It, however, affords passage to the prostatic urethra, its unstriped muscle-fibres are continuous with the vesical muscle at the trigonum and with the circular fibres of the bladder, and both the anatomical and subjective effects of the more common pathological changes in the prostate are observed in relation to the urinary system, with which, therefore, it is most intimately associated.

Injuries of the prostate are rare on account of its protected position, and usually involve also the rectum or the bladder. Hemorrhage from the prostato-vesical plexus may be dangerous in amount ; and if a wound extend upward into the neck of the bladder, that organ may become distended with blood and form a tense, globular hypogastric tumor. Infiltration of urine following a prostatic wound may, in accordance with the situation of the latter, reach the hypogastrium from the prevesical space, the ischio-rectal region or the perineum from coincident division of the fascia of Colles, or the recto-vesical space and the pelvis from similar division of the recto-vesical fascia.

Disease of the prostate, if infectious, is usually gonorrhœal in origin. It is often due to the use of unclean urethral or vesical instruments. It tends to suppuration on account of the very imperfect drainage of the products of inflammation from the numerous follicles.

Prostatitis is attended by (*a*) much swelling, owing to the vascularity and spongy structure of the gland. As the forward enlargement of the prostate is prevented by the resistance of the dense pubo-prostatic ligaments, the subpubic ligament, and the firm superior layer of the triangular ligament, the swelling is greatest in the posterior two-thirds of the gland. Its downward extension is evidenced by (*b*) a sense of weight and uneasiness in the perineum and (*c*) rectal irritation and tenesmus. Its upward and backward spread is shown by (*d*) interference with micturition, due to compression of the prostatic urethra and elevation of the vesical outlet. The symptoms of (*e*) painful and frequent micturition and (*f*) vesical tenesmus are due in part to the mechanical obstruction, but chiefly to the extension of the inflammation to the trigonal region and to the obstruction by pressure of the prostatic venous plexus into which the vesical plexus empties, causing intense congestion of the vesical mucosa. The unyielding character of the prostatic sheath produces (*g*) the heavy, throbbing pain felt in the infrapubic, perineal, and rectal regions, and results in such tension that (*h*) referred pains are very common, and, on account of the derivation of the nerve-supply of the prostate from the lower three dorsal and upper three sacral segments, are apt to be widely distributed, as, *e.g.*, pain over the tip of the last rib (tenth dorsal nerve), over the posterior iliac spine (eleventh dorsal nerve), or even in the soles of the feet (third sacral nerve) (Treves); reflex irritation of the inferior hemorrhoidal nerve may cause intense pruritus ani,—sometimes a very annoying symptom.

Prostatic abscess usually takes the direction of least resistance and opens into the urethra. Its progress towards the pelvis is resisted by the dense investment contributed by the pelvic fascia; towards the perineum, by the superior layer of the triangular ligament. It sometimes points towards the rectum, from which it is separated by a thinner and less resistant layer of the pelvic fascia, and may then open directly into the rectum, or be guided by it to the perineum.

Hypertrophy of the prostate to some degree occurs in about one-third of all males who have passed middle life, and in about one-tenth of all males over fifty-five the enlargement becomes of pathological importance. Its cause is unknown. Various theories having a more or less direct bearing upon its anatomical and physiological characteristics have been advanced to explain its occurrence, but none has been demonstrated. It has been attributed to (*a*) the general arterio-sclerosis of old age (Guyon); (*b*) a primary change in the bladder necessitating a compensatory hypertrophy of the prostate (Harrison); (*c*) a growth analogous to uterine fibromyoma (Thompson); (*d*) the persistence, in an adjunct sexual organ, of physiological activity intended for the control and determination of the masculine characteristics after the need for such activity had disappeared (White); (*e*) an attempt to compensate quantitatively for a qualitative deterioration in the prostatic secretion, whose function (Fürbringer) is to facilitate the mobility and vitality of the spermatozoa (Rovsing); and, recently, (*f*) infection (most often by the gonococcus), aggravating a senile degenerative process (Crandon).

The enlargement may affect chiefly any of the separate components of the prostate, and may thus be adenomatous, myomatous, or fibrous in its character, although usually the glandular element predominates. It may involve particularly the lateral lobes, or may affect almost exclusively the so-called median portion placed at the lower posterior part of the gland, between the ejaculatory ducts. This portion is directly beneath the vesical neck.

The degree of hypertrophy is extremely variable, the prostate being increased from its normal weight of between four and six drachms to a weight of many ounces, and, of course, correspondingly increased in size.

It is not possible here to do more than call attention to these varieties of hypertrophy, but its usual and general effects may be considered with reference to their anatomical causation.

1. The direction of greatest resistance to enlargement is forward (*vide supra*) and next downward (towards the rectum). Hence the growth usually takes place in an upward and backward direction, although the resistance offered by the recto-vesical layer of fascia does not prevent marked extension in that direction in many cases. As a *direct* result of this enlargement there follow: (*a*) compression, flatten-

ing, and elongation of the prostatic urethra, or lateral deviation of that canal (if one lobe greatly exceeds the other in size); (*b*) elevation of the vesical neck and outlet, which are carried up by reason of their intimate connection with the prostate, especially with its median lobe, the base of the bladder remaining relatively unaffected; (*c*) the formation in this manner of a pouch or pocket (post-prostatic pouch) in the bladder at a lower level than the vesical outlet.

The *indirect* results of these conditions are the *changes in the bladder* occasioned by (*a*) the mechanical obstruction which the enlarged prostate offers to the ready and complete evacuation of its contents, (*b*) the circulatory disturbance incident to pressure on the prostatic veins into which the blood from the vesical veins passes, and (*c*) septic infection.

As a result of the narrowing or deflection of the urethra, the elevation of the vesical outlet, and the formation of the post-prostatic pouch, the bladder is not entirely emptied at each act of micturition, a certain amount of *residual urine* remaining behind. This may gradually increase as the obstruction becomes more marked, ultimately causing *dilatation of the bladder*, *with atony* consequent on partial degeneration of its muscular walls, or, in consequence of the more vigorous bladder contraction required to empty the bladder, the trabeculæ may become enormously hypertrophied, the inner layers forming pronounced ridges. These by their contraction exert a powerful pressure upon the vesical contents, which, escaping very slowly, transmit the pressure in all directions and occasion bulgings or sacculations in such weak parts of the bladder-walls as are not supported by muscular bands or by strong investing fasciæ. The *hypertrophy* and *sacculation* are further encouraged by the vesical irritability incident to venous congestion at the neck of the bladder, which, as the prostatic veins become more obstructed, keeps up a condition of passive hyperæmia and erethism more potent than residual urine alone to occasion the frequently recurring desire to urinate and the muscular spasm of the sphincter at the beginning of the act, which calls for such strong and repeated efforts on the part of the detrusor muscles.

Septic infection of a healthy mucous membrane by the pyogenic microbes causing acute or chronic cystitis is not possible, even although such bacteria are present in the urine; when, however, the vesical mucous membrane is congested in consequence of obstruction to venous return, and of distention of the viscus and frequently recurring contractions of the detrusor muscles, it offers but slight resistance to the microbic invasion. The pyogenic microbes are generally carried to the bladder by dirty instruments, or, if these are rendered sterile, through failure to cleanse the anterior urethra before the instrument is introduced into the bladder. Often cystitis develops independently of the use of instruments, probably as a result of infection conveyed by way of the urethral mucous membrane.

2. The *subjective symptoms* brought about by these conditions may be briefly summarized and will be readily understood by reference to the foregoing and to the article on the bladder. (*a*) *Frequent urination*, due partly to the inability completely to empty the bladder, but chiefly to the venous congestion about the trigonum. (*b*) *Difficulty in starting urination*, due to muscular spasm of the external vesical sphincter, which, excited by reflexes from the hyperæsthetic prostatic urethra and neck of the bladder, is not fully under the control of the will. A temporary reflex inhibition of the detrusor muscles may also delay the act of urination. (*c*) *Feeble urination*, due to the weakness, atony, or paresis of the overstretched detrusors. (*d*) *Interrupted urination*, due usually to spasmodic contraction of the external vesical sphincter and compressor urethræ muscles, reflexly excited by urethro-cystitis; occasionally the result of intermittent contraction of the detrusors, often (as in many cases of cardiac palpitation) a sign of beginning muscular atony. The physiology of micturition requires continuous contraction of the detrusor muscles and relaxation of the sphincter *for a brief interval* only. When there is sufficient obstruction to triple or quadruple the time normally required fully to empty the bladder, the detrusor muscles, exhausted by their effort, may relax, whereupon the sphincter muscles, relieved of the *vis a tergo*, promptly contract. After some seconds or minutes the detrusors recover sufficiently to make further efforts at evacuation. (*e*) *Incontinence of urine*, which may always be taken as a symptom of retention with overflow, the intravesical

tension of the overfull bladder being sufficient to overcome the resistance offered by the tonic contraction of the sphincter muscle plus that due to the prostatic enlargement. (*f*) *Complete retention of urine*, due either to an aggravation of the chronic congestion of the urethro-vesical mucosa or to the completion of an atrophic process which has finally destroyed all power of contraction in the bladder. (*g*) *Referred pains*, similar to those noted as occurring in acute prostatic swelling (*vide supra*). (*h*) *Constitutional disturbance*, due to septicæmia or uræmia, or both.

Operations.—*Prostatotomy.*—Incision or puncture of the prostate for the evacuation of an abscess may be made through the rectum or by a median perineal incision. The same name is applied to an operation which consists in opening the urethra at the apex of the prostate by a median perineal incision, and dividing the obstructing portion of the gland by means of a probe-pointed bistoury, cutting from within outward. The channel may be further enlarged by divulsion with the finger. The anatomy and relations of the parts involved have already been described (page 1921).

Of the various operative procedures to which the prostate is subjected, *prostatectomy* is, however, by far the most important. Under this name operations have been described which consist of the removal of the enlarged median lobe, or of portions of one or both lateral lobes, or of the whole prostate, by either perineal or suprapubic routes.

In suprapubic prostatectomy the prostate is approached by means of a suprapubic cystotomy (page 1921). The mucous membrane over the most prominent portion of the intravesical protuberance is scratched through and, as a rule, the growths or the prostate removed by enucleation with the finger.

The possibility of total removal of the prostate, and especially of such removal without coincident injury or removal of the prostatic urethra and ejaculatory ducts, has been vigorously discussed. It has been complicated by confusion as to the structures described as the "capsule" and as the "sheath."

The views of Freyer appear at present to explain most satisfactorily the actual anatomical conditions found at operation, and are thus summarized by him: The prostate is in reality composed of twin organs, which in some of the lower animals remain distinct and separate throughout life, as they exist in the human male during the first four months of fœtal existence. After that period, in the human fœtus, they approach each other, and their inner aspects become agglutinated, except along the course of the urethra, which they envelop in their embrace. These two glandular organs, which constitute the lateral lobes of the prostate, although welded together, as it were, to form one mass, remain, so far as their secreting substance and functions are concerned, practically as distinct as the testes, their respective gland ducts opening into the urethra in the depression on either side of the urethral crest. Each of these two glandular bodies, or prostates, is enveloped by a thin, strong, fibrous capsule; and it is these capsules—less those portions of them that dip inward, covering the opposing aspects of the glandular bodies or lobes, and thus disappear from view, being embedded in the substance of the prostatic mass—that constitute the true capsule of the prostate regarded as a whole. This capsule extends over the entire organ except along the upper and lower commissures, or bridges of tissue, that unite the lateral lobes above and below the urethra, thus filling in the gaps between them. This true capsule is intimately connected with the prostatic mass and incapable of being removed from it save by dissection.

The urethra, accompanied by its surrounding structures,—viz., its longitudinal and circular coats of muscles continued forward from the bladder, its vessels and nerves,—passes forward and upward between the inner aspects of the two glands or lobes and is embraced by them. The ejaculatory ducts enter the prostatic mass close together, in an interlobular depression at the lower part of its posterior aspect, each coursing along the inner surface of the corresponding lobe. They do not penetrate the capsules of the lobes, but pass forward in the interlobular tissue, to open into the urethra.

The prostate, thus constituted and enveloped by its *true capsule*, is further encased in a second capsule or *sheath*, formed by the visceral division of the pelvic fascia, numerous connecting bands passing, however, between the two (Thompson).

Between these two capsules, or rather mainly embedded in the outer one, lies the prostatic plexus of veins, most marked in front and on the sides of the prostate. The larger arteries also lie between the true capsule and the sheath, numerous small branches passing from them through the true capsule for the supply of the prostatic substance.

Freyer illustrates his view by imagining the edible portion of an orange composed of two segments only, instead of several, with the septum between them placed vertically, and says that the thin, strong, fibrous tissue which covers the segments of the orange, and which is intimately connected with the pulp, would then represent the *true capsule* of the prostate, the two segments or halves of the orange being represented by the two lobes of the prostate. Further, the rind of the orange would represent the outer capsule or prostatic *sheath*, contributed by the pelvic fascia. In the method of suprapubic prostatectomy now known by his name, it is the true capsule as above described that is removed, the sheath being left behind, thus preventing infiltration of urine into the cellular tissues of the pelvis.

In most cases of hypertrophy of the prostate the overgrowth is adenomatous in character, numerous encapsuled adenomatous tumors being found embedded within the substance of the lobes and frequently protruding on their surfaces. They sometimes assume the form of polypoid outgrowths, which, however, are invariably enclosed within the true capsule, which is pushed before them.

As the lobes enlarge they bulge out and have a tendency, each enclosed within its own capsule, to become more defined and isolated, thus recalling their separate existence in early fœtal life. They become more loosely attached along their commissures (particularly the upper one), which in the normal prostate unite them above and below the urethra. And in the course of this change the urethra, with its accompanying structures, is loosened from its close attachment to the inner surfaces of the lobes, thus facilitating its being detached and left behind uninjured in the removal of the prostate.

In the earlier stages of the adenomatous overgrowth the enlargement is probably entirely extravesical. Its expansion in this position is, however, limited by the pubic arch above, the triangular ligament in front, and the sacrum below. As the enlargement progresses, it advances in the direction of least resistance,—namely, into the bladder. The sheath, which at the posterior aspect of the prostate is least defined, becomes gradually thinner as the enlargement in this direction progresses, till eventually the prostate has burst through it, and is then merely covered by the mucous membrane of the bladder (Freyer).

It has been asserted that what has here been called "capsule" is in the normal prostate really only a thin outer non-glandular portion—cortex—containing both muscular and fibrous tissue (Shattock), and that the envelope formed from the prostate by the expansion of adenomata represents more than the "cortex" and contains glandular tissue derived from the stretched and compressed outer portion of the prostate (Wallace).

However this question may ultimately be settled, the anatomical views set forth above explain the separability of the mass of the prostate from (*a*) the prostatic plexus of veins (avoiding hemorrhage), (*b*) the under surface of the recto-vesical fascia (avoiding urinary infiltration), and (*c*) the prostatic urethra and ejaculatory ducts (minimizing interference with micturition and with potency), which separability has been shown to be at least occasionally possible during operation.

Perineal prostatectomy is done, with the patient in the lithotomy position, by means of a semilunar incision in front of the anus carried down through the successive structures of the urethral perineum until the sheath of the prostate is reached. After division of the sheath on either side in a direction parallel with the medial fibres of the levator ani, the prostate in its capsule—or portions of it—may be enucleated with the finger. The gland may be made more accessible by downward pressure through the space of Retzius (by means of a suprapubic incision) or through the bladder itself (after a preliminary suprapubic cystotomy). It may be reached by a lateral incision half encircling the anus. It should be remembered that it is separated from the ischio-rectal fossa only by the levator ani muscle, with the visceral layer of the pelvic fascia on its upper and the anal fascia on its lower surface.

THE GLANDS OF COWPER.

Cowper's glands (**glandulae bulbourethrales**) are two small ovoid bodies situated along the under surface of the membranous portion of the urethra (Fig. 1632), one on either side of and close to the mid-line. In general form and size (from 5–8 mm. in diameter) they resemble a pea, although their contour is irregular and somewhat knobbed. Their color is reddish yellow and their consistence firm. They lie within the deep perineal interspace between the two layers of the triangular ligament embedded within the fibres of the compressor urethræ muscle.

The *ducts* of the glands—about 1.5 mm. in diameter and from 3–4 cm. in length—run forward and medially, at first between the bulbus spongiosum and the membranous urethra, then within the bulb itself, and, finally, for about 2 cm. beneath the urethral mucous membrane to open by small slit-like orifices on the lower wall of the bulbus urethræ near the mid-line. The position of these inconspicuous openings is sometimes masked by a fold of mucous membrane or a slight depression. Quite frequently the two ducts unite and open by a common orifice.

Structure.—These glands are mucous tubo-alveolar in type, their terminal divisions ending, after more or less branching, in irregularly sacculated compartments. In places the latter communicate by means of a reticulum of connecting canals (Braus). The *alveoli* are lined with low columnar or pyriform epithelial cells, among which mucus-secreting cells are plentiful. The cuboidal epithelium that clothes the smaller ducts and the dilatations connected with them gives place to clear columnar cells within the larger excretory canals. The divisions of the gland are united by interlobular connective tissue and invested in a general fibrous envelope in which a considerable quantity of unstriped muscle occurs. The *secretion* of Cowper's glands, clear and viscid and of alkaline reaction, is probably of service in maintaining favorable conditions for the spermatozoa by neutralizing acidity of the urethral canal due to passage of urine (Eberth). In addition to their recognized homology with the glands of Bartholin in the female, the observed histological changes incident to sexual excitation warrant the grouping of these glands as accessory sexual organs.

Vessels.—The *arteries* supplying Cowper's glands are twigs given off from the arteries of the bulb as they course between the two layers of the triangular ligament. The *veins* are tributary to those returning the blood from the bulbus spongiosum which empty into the internal pudic. The *lymphatics* are afferents to the internal iliac lymph-nodes.

The **nerves** are derived from the pudic.

Development.—The bulbo-urethral glands appear about the end of the third month of fœtal life as solid outgrowths from the entoblastic lining of the urogenital sinus. With the elongation of the latter incident to the formation of the male urethra and the penis (page 2044), the glands assume a lower position and their ducts are correspondingly lengthened. During the first ten or twelve years the glands undergo only small increase in volume, but between the sixteenth and eighteenth years they attain their full size. In aged subjects they atrophy and are frequently so small that their recognition is difficult.

Variations.—In addition to abnormalities in size, the two glands may be fused into a single mass, or one or both may be wanting. Sometimes their absence is only apparent, since the organs may be represented by rudimentary glands embedded entirely within the substance of the corpus spongiosum.

THE FEMALE REPRODUCTIVE ORGANS.

The reproductive organs of the female comprise two groups—the *internal*, situated for the most part within the pelvis and above the pelvic floor, and the *external*, embraced by the subpubic arch and below the triangular ligament and supported by attachments to the surrounding bones, fascia, and integument. The internal organs are the sexual glands, the *ovaries*, which produce the ova, the oviducts or *Fallopian tubes*, the canals conveying the sexual cells, the *uterus*, and the *vagina*, the passage which, beginning within the pelvis, embraces the lower end of the uterus above, pierces the pelvic floor, and ends below within the external genital cleft. The Fallopian tubes, uterus, and vagina represent the excretory canals of the sexual glands which in the embryo, as the Müllerian ducts, for a time are separate. After fusion of their lower segments has taken place, the unpaired tube thus formed becomes the vagina and the uterus, the latter being specialized for the reception and retention of the fertilized ovum during gestation.

The external organs, often termed collectively the *vulva* (**pudendum muliebre**), include the *clitoris*, the *labia*, and the enclosed *vestibule* and *vaginal orifice* and the *glands of Bartholin*. In a general way these parts represent structures homologous with the penis and scrotum, but in a less advanced and specialized stage of development.

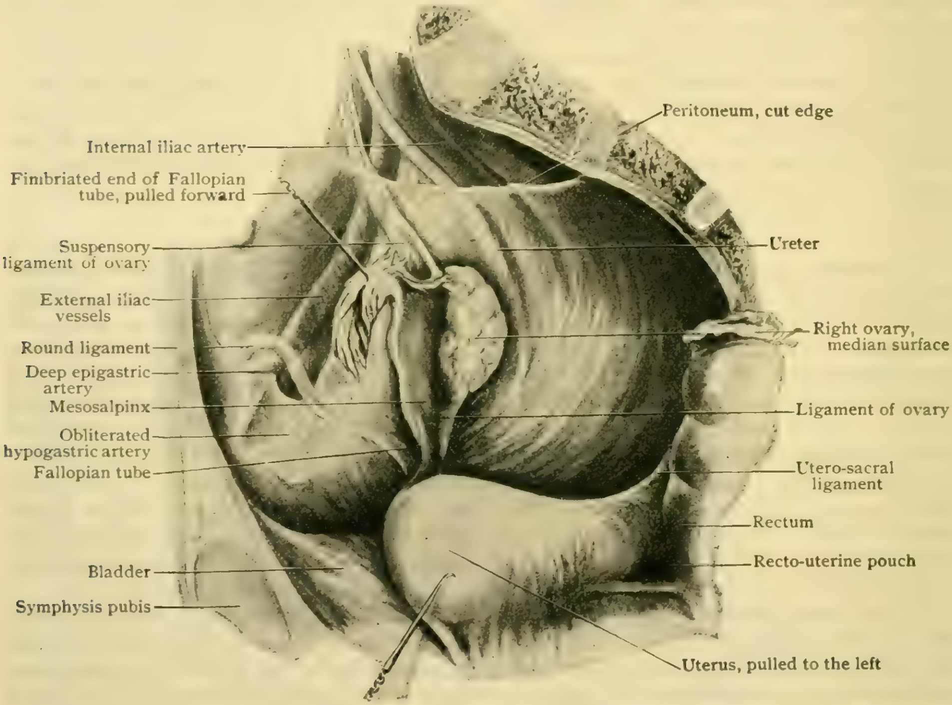
THE OVARIES.

The ovary (**ovarium**), one on either side of the body, is the sexual gland proper, within and from which are developed and liberated the mature maternal sexual cells, the ova. It is a solid body, resembling in form a large almond, and in the adult lies against or near to the lateral pelvic wall invested by peritoneum continued from the posterior surface of the broad ligament of the uterus. Even when mature, the organ presents considerable individual variations in size, its average dimensions being 36 mm. (1½ in.) in length, 18 mm. (¾ in.) in breadth, and 12 mm. (½ in.) in thickness. Variations in size include a length of from 2.5–5 cm. (1–2 in.), a width of from 1.5–3 cm. (⅝–1⅜ in.), and a thickness of from .6–1.5 cm. (¼–⅝ in.), according to German authorities. The right ovary is frequently somewhat larger than the left. The adult organ weighs about 7 grm. (¼ oz.). After the cessation of menstruation, about the forty-fifth year, the ovary decreases in size and weight, in old women being reduced to one-half or less of its normal proportions.

The ovary presents two **surfaces**—a *median* (**facies medialis**), directed inward, and a *lateral* (**facies lateralis**), looking outward and in more or less close relation with the pelvic wall; two **margins** connecting the surfaces—an *anterior* (**margo mesovaricus**), which is thin, straight, and attached to the posterior surface of the broad ligament by a short peritoneal fold or mesovarium, and a *posterior* (**margo libra**), which is thicker, rounded, convex, and unattached; and two **poles**—an *upper* (**extremitas tubaria**), rounded, embraced by the oviduct and attached to the suspensory ligament of the ovary and usually to the fimbriated extremity of the Fallopian tube, and a *lower* (**extremitas uterina**), pointed and attached to the uterus by a fibromuscular band, the utero-ovarian ligament. The portion of the attached anterior border through which the vessels and nerves enter and emerge is known as the *hilum* (**hilus ovarii**). The surfaces of the mature ovary are not even, as in early life, but modelled by rounded elevations of uncertain number and size and by irregular pits and scars. The elevations are produced by the underlying Graafian follicles in different stages of growth, while the irregular scar-like areas indicate the position of corpora lutea of varying age and development. Just behind the attachment of the mesovarium and parallel to the hilum, the surfaces of the fresh ovary are crossed by a narrow stripe of lighter color, straight or curved and often slightly raised. This band, the *white line of Farre*, marks the transition of the usual peritoneal endothelium into the cylindrical germinal epithelium that covers the exterior of the organ and appears dull and lacking in the lustre characteristic of serous surfaces.

Position and Fixation.—Although subject to deviations due to the influence of other organs, especially the pull of the uterus, and of pregnancy, the long axis of the normally placed ovary, in the erect posture, is approximately vertical (Fig. 1684). The margin attached to the broad ligament of the uterus is directed forward and slightly outward and the free convex border backward and inward. The outer surface usually lies in contact with the peritoneum covering the lateral pelvic wall within a more or less well-marked depression, the *ovarian fossa* (**fossa ovarica**). This recess, triangular in its general outline and variable in depth, is included within the angle formed by the diverging peritoneal folds covering the external and internal iliac vessels. In favorable subjects, in which the amount of subperitoneal fat is small and the embedded structures, therefore, not masked, the ureter and the uterine artery will be seen forming the immediate boundary of the ovarian fossa behind, while above and in front extends the remains of the obliterated hypogastric artery. Below, where its

FIG. 1684.



Right lateral wall of pelvis, showing ovary in position; Fallopian tube has been pulled forward and uterus to the left.

boundary is indistinct and uncertain, it fades into the pelvic floor, often without demarcation. The floor of the fossa is obliquely crossed by the obturator vessels and nerve. Within this depression the ovary lies, hidden to a considerable extent beneath the oviduct, which arches over the upper pole and largely covers the median surface with its expanded fimbriated end. The upper or tubal pole reaches almost to the level of the external iliac vein and the pelvic brim, and is overhung by the inner edge of the psoas muscle. The lower pole rests upon the upper (posterior) surface of the broad ligament and nearly touches the pelvic floor—about 2 cm. above and in front of the upper border of the pyriformis muscle and the trunk of the greater sciatic nerve (Rieffel).

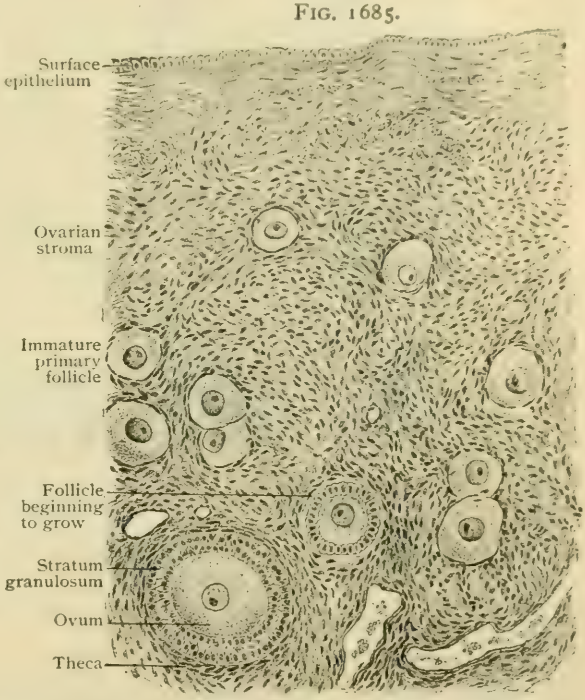
The vertical position of the ovary is maintained by the *suspensory ligament* (**ligamentum suspensorium**), also called *infundibulo-pelvic ligament*, which is a triangular band of fibro-muscular tissue, attached to the upper tubal pole of the ovary and invested by a peritoneal fold continued from the upper and outer corner of the broad

ligament. It passes outward across the external iliac vessels in front of the sacro-iliac articulation and is lost in the fascia covering the psoas muscle. Embedded within the enclosed fibro-muscular tissue lie the ovarian vessels and nerves, which thus gain the broad ligament in their passage to the ovary.

The anterior margin of the ovary is attached to the posterior surface of the broad ligament by a short but broad band—the *mesovarium*—covered on both sides by peritoneum, that conveys the ovarian vessels proper and the nerves to the hilum through which they enter and emerge from the organ. The somewhat pointed lower end of the ovary is connected with the posterior border of the uterus, between the oviduct and the round ligament, by a cord-like band, the *utero-ovarian ligament* or *ligament of the ovary* (ligamentum ovarii proprium). This band, from 3–4 mm. thick, lies within the posterior layer of the broad ligament beneath the peritoneum, through which it is seen as a distinct cord.

Since the uterus and its broad ligament are subject to continual changes of position, the attachment of the ovary to these structures often produces deviations from its typical location. These influences affect particularly the lower pole, the upper enjoying greater fixation from the support afforded by the suspensory ligament. Asymmetry in the position of the two ovaries is usual, as the fundus of the uterus seldom lies strictly in the mid-line, and hence the lower pole of the ovary of the opposite side is dragged medially. The long axis of the ovary, under such conditions, is oblique on the side opposite to that towards which the uterus is deflected. Conversely, relaxation of the ligaments occurs on the side towards which the uterus tends and thus favors the retention of the vertical position of the ovary. Notwithstanding the latitude of movement possible, the position of the normal ovary is fairly constant, the close relation of the oviduct to the median surface, aided by the pressure exerted by other organs within the pelvis, materially assisting in retaining the ovary within its fossa. The stretching and subsequent relaxation of the suspensory ligament incident to pregnancy are predisposing causes of displacement of the ovary due to insufficient fixation.

FIG. 1685.



Section of cortex of ovary of young woman, showing primary and growing follicles within ovarian stroma. × 190.

Structure.—The ovary consists of two principal parts, the *cortex* (zona parenchymatosa)—a narrow superficial zone, from 2–3 mm. thick, that forms the entire periphery of the organ beyond the white line; and the *medulla* (zona vasculosa,) that embraces the deeper and more central remaining portion of the gland. The cortex alone contains the characteristic Graafian follicles and the ova, while the medulla is distinguished by the number and size of the blood-vessels, especially the veins.

The **cortex**, as seen in vertical sections of the functionally active organ, consists chiefly of the compact *ovarian stroma* that is composed of peculiar spindle-shaped connective tissue-cells, from .015–.030 mm. in length and about one-fifth as much in width, and fibrillar intercellular substance. The *stroma-cells*, which somewhat resemble the elements of involuntary muscle in appearance, are arranged in

bundles that extend in all directions (chiefly, however, obliquely vertical to the surface) and are seen cut in different planes. Immediately beneath the germinal epithelium covering the surface, the stroma-elements are disposed with greater regularity and form a compact superficial stratum, the *tunica albuginea.* Embedded within the stroma lie the most characteristic components of the cortex, the *egg-sacs* or *Graafian follicles.* These are seen in different stages of development, but for the most part are small, inconspicuous, and immature, in the human ovary being much fewer and less prominent than in many other mammals. Corresponding with their stages of development the egg-sacs may be divided into *primary*, *growing*, and *maturing follicles.* In general, the youngest lie nearest the surface, the more advanced deeper and towards the medulla, while those approaching maturity appear as huge vesicles that occupy not only the entire thickness of the cortex, but often produce marked elevation of the free surface.

Fig. 1686.

Section of medulla of ovary, showing numerous blood-vessels and fibro-muscular stroma. × 75.

The **medulla**, the vascular zone of the ovary, consists of loosely disposed bundles of fibro-elastic tissue supporting the blood-vessels, lymphatics, and nerves. In the mature organ, with the exception of the encroaching ripening Graafian follicles, egg-sacs are not found within the medulla. The larger vessels are accompanied by bundles of involuntary muscle prolonged from the utero-ovarian ligament through the mesovarium and the hilum into the medulla. The veins are particularly large and appear in sections as huge blood-spaces of irregular outline in consequence of their tortuosity and plexiform arrangement.

Follicles and Ova.—The immature *primary follicles* (**folliculi oophori primarii**) are microscopic in size (from .04–.06 mm. in diameter) and vary greatly in number, the estimate for the two ovaries of young adults being placed at approximately 35,000 (Bonnet). Each follicle consists of the centrally situated young *egg* (**ovulum**) surrounded by a single layer of flattened epithelium or *mantle cells* (Fig. 1685). Immediately outside the latter lies the stroma, in the interstices of which the young egg-sacs are lodged. The *primary ova* are approximately spherical and measure from .035–.045 mm. in diameter in ordinary sections, but a third more in the fresh unshrunken condition (Nagel). They possess a finely granular cytoplasm, a centrally placed spherical nucleus, about .016 mm. in diameter, and a nucleolus. The primary ova may remain for years, sometimes from early infancy to advanced age, practically unchanged, until they undergo either atrophy, as do most of them, or further growth leading, under favorable conditions, to the development of the mature sexual cell. Of the thousands of primary eggs contained in the ovaries just before puberty, only comparatively few attain perfection. Sooner or later, but at some uncertain time, the primary follicles enclosing ova destined for complete development enter upon a period of active growth, the earliest indication of which is the conversion of the flat mantle cells of the egg-sac into a single layer of cuboid epithelium.

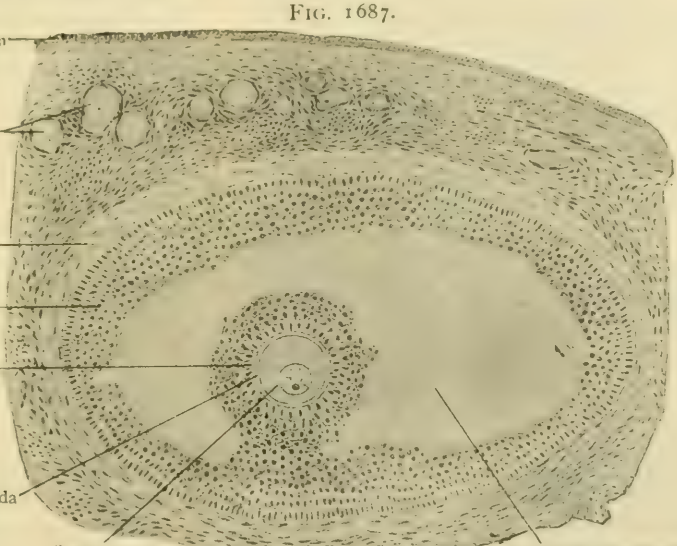
In addition to increasing size, the *growing follicles* are distinguished by rapid proliferation of the cuboid epithelium, which results in the production of a stratified *follicular epithelium* that surrounds the ovum. Outside these polygonal elements the stroma becomes condensed into a connective-tissue envelope or *theca* (**theca folliculi**). Increasing in thickness, the latter is subsequently differentiated into two layers, an *outer* (**tunica externa**), consisting of con-

centrically disposed connective-tissue fibres, and an *inner* (**tunica interna**), composed of round and spindle cells, and provided with numerous capillaries. After the follicular epithelium has been formed, the ovum itself begins to grow, the expansion proceeding uniformly and affecting all parts of the cell, including nucleus and nucleolus. It attains its maximum diameter comparatively early and long before the follicle has reached full growth. Through the agency of the follicular epithelium, the egg becomes invested with a protecting envelope, the *zona pellucida*, after which little or no further increase in the size of the ovum takes place (Nagel).

At first solid, the growing follicle is converted into a vesicle containing fluid by the vacuolation and breaking down of cells within the middle layers of the follicular epithelium, the resulting clefts fusing into a common space. The intra-epithelial cavity so formed contains accumulating fluid, the *liquor folliculi*, that is supplied by the continued proliferation, vacuolation, and destruction of the follicle cells and by the transudation from the surrounding blood-vessels. This fluid increases in amount to such an extent that it soon occupies the greater part of the expanding egg-sac, now entering upon its final stage of growth.

The *maturing follicles* (**folliculi oophori vesiculosi**) occupy the deeper parts of the cortex and reach to the medulla. With their expansion and consequent requirement of space, the vesicles seemingly rise, appropriating more and more of the cortex, until the entire thickness of the latter, and sometimes a part of the medulla in addition, is occupied by the ripe follicle, which just before its final rupture attains a diameter of from 1–2 cm. or more, and appears on the

FIG. 1687.



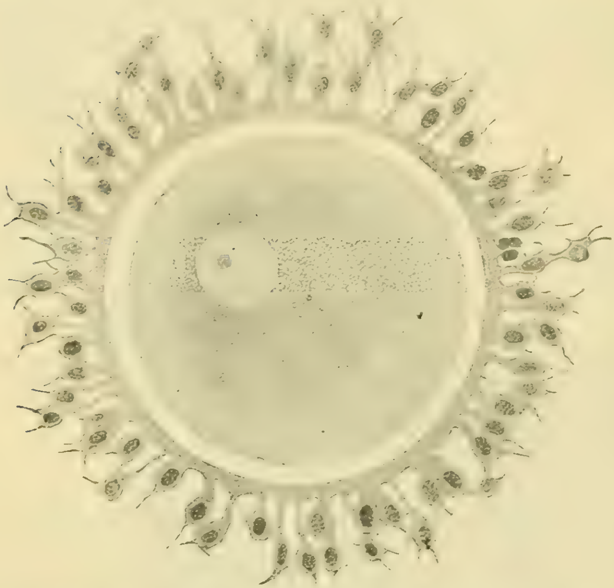
Section of ovary, showing partially developed Graafian follicle. × 100.

free surface of the ovary as a tense rounded elevation. After liberation of the ovum, the follicle is converted into the conspicuous *corpus luteum* (page 1990).

Seen in section, the wall of the ripe follicle, now known as the *Graafian follicle*, consists of a well-developed capsule or *theca* (from .14–.20 mm. in thickness), of which the outer layer is a lamellated fibrous membrane, and the inner tunic is composed of looser connective tissue containing numerous peculiar large cells which, as maturity approaches, exhibit granularity and a faint yellowish color. Next the inner layer of the capsule lies a delicate *membrana propria*, against the inner surface of which is applied the *stratum granulosum*, composed of the outer layers of the follicular epithelium that bound externally the fluid-space of the vesicle. At one point, always opposite the place where the follicle ruptures (stigma), the stratum granulosum is prolonged into a pedunculated spherical mass of epithelial cells that projects into the cavity occupied by the liquor folliculi. This mass (**cumulus oophorus**) contains the egg and on section appears as a ring (*discus proligerus*) that encircles the zona pellucida and the enclosed ovum and consists of two or three layers of epithelial cells. Those next the zona are elongated, with their ends directed towards the ovum pointed and prolonged into delicate processes that are attached to or penetrate within the *zona pellucida*. The latter, from .007–.011 mm. in thickness, is the product of the surrounding follicular cells and does not form a part of the ovum proper. The radial striations which the envelope sometimes exhibits (hence the name, *zona radiata*, under which it is often described) are probably due to the processes of the epithelial cells and not to the existence of minute canals (*micropyles*) seen in the eggs of many lower animals.

The **human ovum** when about to be liberated from the Graafian follicle possesses a diameter of from .16–.20 mm. Its cytoplasm, or *vitellus*, exhibits differentiation into a peripheral *protoplasmic* and a central *deutoplasmic* zone. According to Nagel, within the former are to be distinguished a narrow slight superficial marginal layer, apparently homogeneous and free from yolk-particles, and a finely granular zone containing minute and scattered deutoplasmic granules. The dark or central deutoplasmic zone is conspicuous on account of the irregular refraction of the enclosed yolk-particles that represent the important nutritive materials for the embryo contained in the eggs of birds and reptiles, but which in the mammalian ovum, especially in that of man, have been for the most part lost during the evolution of the higher types. Beyond a slight condensation of the surface, the presence of a distinct cell-wall, or *vitelline membrane*, in the mammalian ovum is doubtful. In the fresh condition the egg-cytoplasm is usually closely applied to the zona pellucida (Ebner), the narrow intervening cleft that is sometimes seen being the *perivitelline space*. Embedded within the deutoplasmic zone, and always eccentrically placed, lies the spherical *germinal vesicle*, as the egg-nucleus is termed. The vesicle measures from .030–.045 mm. in diameter, is bounded by a sharply defined double-contoured nuclear membrane, and contains the *germinal spot* or nucleolus (from .004–.008 mm.) and the nuclear reticulum.

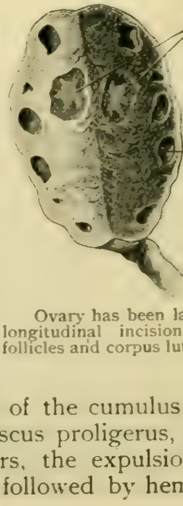
FIG. 1688.



Almost mature human ovum taken from fresh ovary. Ovum, with germinal vesicle and spot, is encircled by clear zona pellucida, which is surrounded by cells of the follicular epithelium. × 300. (*Waldeyer*.)

Corpus Luteum.—The causes leading to the final rupture of the Graafian follicle are still uncertainly known, although in the light of later researches the older view, attributing the bursting of the ripe vesicle to mechanical overdistention induced by accumulation of the liquor folliculi, is inadequate. According to Nagel, when the follicle approaches maturity the inner layer of the theca becomes the seat of great activity. The blood-vessels increase in size and number and the cells undergo not only rapid proliferation, but extraordinary growth, the enlarged elements becoming filled with a peculiar yellowish substance and transformed into *lutein cells*.

FIG. 1689.



Ovary has been laid open by longitudinal incision, exposing follicles and corpus luteum.

In consequence of this activity, the formerly smooth theca becomes thickened and wavy and projects into the cavity of the follicle as vascular papillæ and ridges. The encroachment thus effected gradually forces the contents of the vesicle towards the surface and that part of the distended follicular wall possessing least vitality and resistance, until, finally, rupture takes place. Coincidently with the proliferation of the lutein cells, the follicular epithelium undergoes fatty change which results in the breaking down of the cumulus and the setting free of the ovum, encircled with the cells of the discus proligerus, into the cavity of the egg-sac. When rupture of the follicle occurs, the expulsion of the egg and the epithelial cells immediately surrounding it is followed by hemorrhage

into the cavity of the former egg-sac, which now becomes converted into a corpus luteum.

The latter, long known as the *corpus luteum verum* when associated with pregnancy, grows to huge dimensions and forms a conspicuous oval mass that may approach 3 cm. in length and occupy a considerable part of the entire cortex. When impregnation does not take place, the yellow body (now called the *corpus luteum spurium*) is smaller, seldom exceeding 1.5–2 cm. in diameter. The classic distinction of "true" and "false," apart from difference of size, has no anatomical basis, since both forms possess identical structure. The assumption that the presence of a large corpus luteum is positive proof of the existence of pregnancy, must be accepted with caution, since yellow bodies of unusual size are sometimes observed in ovaries of virgins.

Shortly after the rupture of the follicle and the replacement of its contents by blood, the opening in the wall of the egg-sac is closed. The rapid proliferation and growth of the lutein cells produces an irregularly plicated wall of increasing thickness that encloses the remains of the degenerating follicular epithelium (granulosa) and invades the hemorrhagic mass. The latter is gradually absorbed until, finally, the encroaching projections of lutein cells and connective tissue meet and the cavity of the follicle obliterated, its former position being subsequently indicated by a central core of connective tissue. The cells of the stratum granulosum, the original epithelial lining of the egg-sac, entirely disappear and take no direct part in the formation of the corpus luteum, their function during the development of the Graafian follicle having been to contribute the liquor folliculi (Schottlaender). Along with the proliferating masses of lutein cells, strands of connective tissue are carried inward from the theca, whereby, after a time, the yellow body becomes broken up by numerous radially disposed vascular septa and their prolongations. With the production of a solid corpus luteum and the absorption of the blood (evidences of which latter for a long time remain as hematoidin crystals), the active *rôle* of the lutein cells is finished. These elements now lose their distinctive yellow pigment (*lutein*), undergo fatty metamorphosis, and finally entirely disappear. With the subsequent shrinking and decrease in the vascularity of the corpus luteum, the connective tissue, which now constitutes the entire mass (*corpus fibrosum*), undergoes hyaline change, becoming clear and non-fibrillar. In consequence the aging corpus luteum loses its former appearance and is transformed into an irregular body, light in color and sinuous in outline, sometimes known as the *corpus albicans* (Fig. 1691). This gradually suffers absorption, but remains for a considerable time, especially when associated with pregnancy, as a conspicuous light corrugated area within the cortex, the last traces of its scar-like tissue finally disappearing in the ovarian stroma. The greatly increased vascularity, within the wall of the ripe Graafian follicle and later around the corpus luteum, subsides as the yellow body

FIG. 1690.

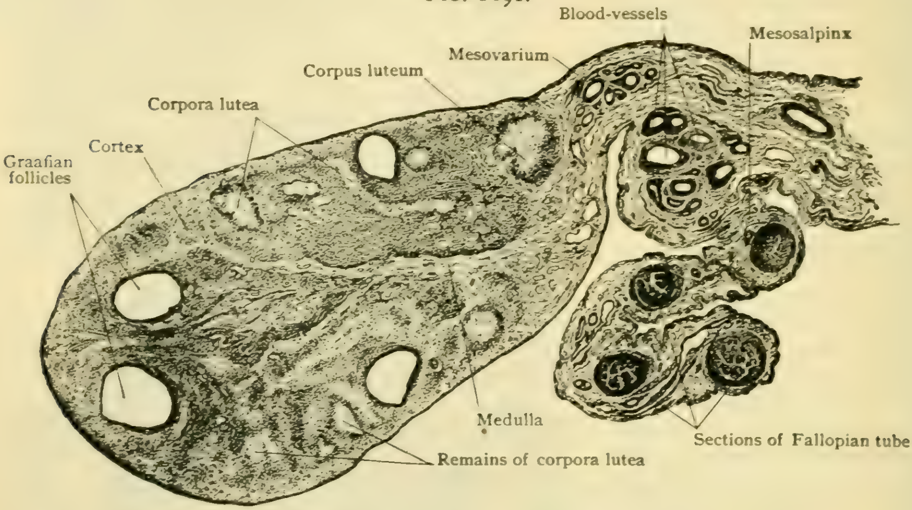
Section of human corpus luteum. × 70.

undergoes regression, until all the new vessels concerned in its nutrition have disappeared and the circulation of that particular part of the ovary is permanently reduced.

The function usually ascribed to the corpus luteum is that of filling the empty follicles and thus restoring the equilibrium of circulation and tension. Clark[1] regards the corpus luteum as a preserver of the circulation, since, when performing its functions most perfectly (during the earlier years of menstrual life), it effects the elimination of the effete follicle and the superfluous blood-vessels without leaving dense and disturbing scars. It is probable, however, that the corpus luteum plays a more important rôle and that it functions as an organ of internal secretion, producing substances influencing the formation of the uterine deciduæ and the proper fixation of the fertilized ovum. Moreover, it may be related to lactation.

The origin of the lutein cells has long been a subject of discussion, and even at present two opposed views share the support of eminent anatomists. According to the older theory, advanced by Baer, these cells are modified connective-tissue elements, derived from the pro-

FIG. 1691.



Cross-section through ovary, oviduct, and part of broad ligament. × 6.

liferation of the cells of the inner layer of the theca folliculi. The other view, formulated by Bischoff, regards the lutein cells as modified follicular epithelium. In the foregoing sketch of the corpus luteum, the lutein cells are ascribed to the theca, a conclusion based upon the convincing observations of Nagel, Rabl, and Clark, and confirmed by the writer's own studies. Sobotta, on the other hand, is most positive in his support of the follicular origin of the lutein cells, based upon an exhaustive investigation on the ovaries of the mouse and rabbit. The difficulty of obtaining human corpora lutea in the earliest stages places the conclusions as to man not beyond challenge.

Vessels.—The *arteries* supplying the ovary are four or five branches that arise from the anastomosis of the ovarian artery with the ovarian branch of the uterine. The trunks (*aa. ovaricæ propriæ*) given off from this anastomotic arch pass to the ovary between the layers of the mesovarium and, entering through the hilum as closely grouped tortuous vessels, reach the medulla. According to Clark,[2] whose description is here followed (Fig. 1692), immediately after gaining the medulla each stem divides into two branches, the *medullary* or *parallel arteries*, that proceed in a direct course towards the opposite free margin of the organ, lying just beneath the cortex, to which they distribute *cortical branches* at regular intervals. In their course to the periphery the cortical branches, losing the characteristic corkscrew-like twistings of the parent stems, supply hundreds of *follicular twigs* to the egg-sacs, each of the latter being provided with a rich vascular net-work anastomosing with two or more follicular branches—an arrangement of great importance in assuring an adequate blood-supply for the growth of the follicle (Clark). At the periphery, the cortical arterioles pass into the veins through an intervening capillary net-work.

[1] Archiv f. Anat. u. Physiolog., Anat. Abth., 1898.
[2] Welch Anniversary Contributions, 1900.

The *veins* follow the general arrangement of the arteries within the cortex and medulla; the pairs of parallel veins, however, do not unite into single stems, but emerge from the hilum as independent tortuous trunks. Within the mesovarium they are interwoven with the bundles of involuntary muscle, and when distended present a conspicuous venous complex (*bulbus ovarii*). The veins proceeding from the ovary (*vv. ovaricæ propriæ*) become tributary to both the uterine and the ovarian (pampiniform) plexus.

The *lymphatics* begin in the cortex as net-works within the thecæ surrounding the Graafian follicles and as lymphatic clefts within the ovarian stroma. From these radicles the larger and irregular channels enter the medulla, where they form converging stems that follow the blood-vessels and leave the hilum of the ovary usually as nine larger trunks (Polano) that pass upward along the free border of the suspensory ligament and empty into the lumbar lymph-nodes surrounding the aorta. Occasionally, but by no means constantly, the ovarian lymphatics communicate with those from the fundus of the uterus and the oviduct.

The **nerves** supplying the ovary are derived from the sympathetic plexus surrounding the ovarian artery (plexus arteriæ ovaricæ), which, in turn, is formed by contributions from the renal and aortic plexuses and corresponds to the spermatic plexus in the male. The small nerve-trunks, composed for the most part of non-medullated fibres, accompany the arteries through the hilum into the ovary, where they are distributed chiefly to the walls of the blood-vessels, around the larger of which terminal plexuses are formed. From the fairly close plexus within the cortex, additional minute twigs pass to the periphery, to end in close relation with the surface (germinal) epithelium, and others to the follicles. The ultimate relation between the latter and the surrounding net-works is uncertain, but it is probable that the nerve-fibrillæ end in the walls of the follicular blood-vessels and do not penetrate beyond the inner tunic of the theca, the terminations within the follicular epithelium described by some observers needing confirmation. Sensory fibres are probably contained within the cortical branches. The claimed existence of minute, true, sympathetic ganglia within the medulla, has not been established.

FIG. 1692.

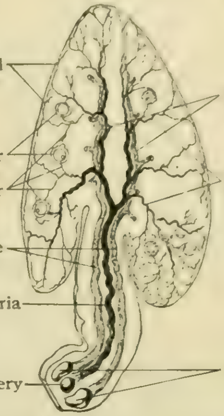


Diagram illustrating arrangement of blood-vessels of ovary. (*Clark.*)

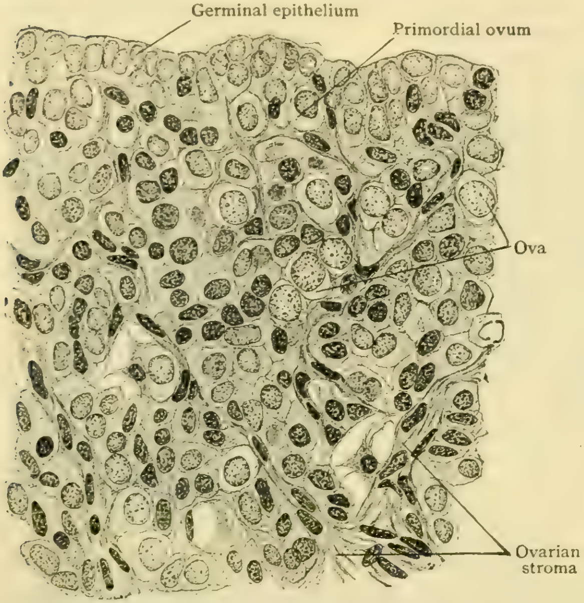
Development.—The primary development proceeds from the indifferent germinal ridge which is early formed on the median surface of the Wolffian body (page 2038). Whether, as usually accepted, the ova in common with the follicular epithelium are directly derived from the modified mesothelium (germinal epithelium) covering the sexual ridge, or are the descendants of germ-cells early set apart from the somatic cells for the special rôle of reproduction, remains to be decided, although evidence in support of this latter hypothesis—the continuity of the germ-cells—is accumulating from observations on the lower animals, in which the origin of the primordial sex-cells is less obscured.

In human embryos of 12 mm. in length, among the cells of the germinal ridge, certain elements are already distinguished by their exceptional size and large, clear nuclei. These are the primary sexual cells, the *primordial ova* (Fig. 1717), usually regarded as originating from the transformation of the germinal epithelium. At first the latter and the subjacent stroma of the Wolffian body are well differentiated from each other. This demarcation is soon lost in consequence of the active intergrowth which takes place between the proliferating germinal epithelium and the ingrowing vascular connective tissue of the Wolffian body—the two chief factors in the histogenesis of the ovary.

As the mass of epithelial elements increases, it becomes broken up by the connective-tissue strands into large tracts, composed of the primary ova surrounded by

multitudes of the smaller and less specialized cells of the germinal epithelium. The larger tracts are subdivided into smaller spherical cell-aggregations (the *egg-balls* of Waldeyer) by the continued intergrowth and mutual invasion of the tissues, and the "egg-balls," in turn, are broken up by the same process until the final division results in the isolation of the ultimate groups, the primary follicles, that include the primary ova surrounded by a single layer of flattened germinal epithelium. In places the larger compartments are cylindrical and attached to the germinal epithelium, appearing as solid outgrowths connected with the surface; to them Pflüger gave the name "egg-tubes" and attributed an aggressive invasion. Since the connective tissue of the Wolffian stroma first invades the deeper stratum of the germinal epithelium, this region, the future medulla of the ovary, is subdivided into the ultimate groups of cells, the primary follicles, earlier than the more superficial and younger layers, this genetic relation being seen in the fully developed ovary, in which the youngest and least mature follicles always occupy the peripheral zone. The most superficial stratum of the germinal ridge remains as the germinal epithelium that covers the exterior of the ovary and replaces the usual peritoneal mesothelium plates.

FIG. 1693.



Section of developing ovary from human embryo, showing intergrowth between germinal epithelium and stroma tissue derived from Wolffian body. × 560.

The details of the transformation of the primary follicles, consisting of the ovum and the investing single layer of mantel-cells, into the ripening Graafian follicles have been described (page 1988). Of the thousands of primary follicles within the young ovary (overestimated by Waldeyer at 100,000 in the two ovaries of the new-born child) very few reach maturity, and by advanced life nearly all have disappeared. This reduction begins during intrauterine life and first affects the follicles situated within the deeper parts of the ovary destined to become the medulla, from which the ova are later entirely absent. The remains of these early follicles probably account for certain of the minute epithelial bodies occasionally seen in the medulla of young adults.

Numbers of follicles within the cortex also are continually undergoing destruction. This affects especially the primary follicles while they lie naked within the stroma, and are unprovided with a theca, the ovum undergoing hyaline degeneration and, along with the mantel-cells, finally entirely disappearing within the ovarian stroma. Beginning in the young ovary long before puberty, as well as throughout the period of sexual maturity, certain egg-sacs are continually transformed, more or less fully, into Graafian follicles that develop to a certain stage and are then arrested, after which they enter upon regression, degenerate, and finally may completely disappear. This process, known as atresia of the follicles, is probably closely related to alterations in their blood-supply (Clark).

With possibly few exceptions, the formation of new follicles ceases during the first few years after birth, the supply developed early in life being in such lavish excess of all possible needs that ample provision is made against dearth of reproductive cells. Infrequently follicles are encountered in which two or more ova are present. This condition results from the inclusion of more than a single primary egg when the follicle was formed, and not from division of an ovum already enclosed, since after the mantel-cells surround the ovum it is

doubtful whether the latter ever undergo division. In certain cases it is also possible that the delicate partition separating two closely applied follicles may disappear, the ova thence occupying the common sac (Ebner.)

The *changes in form and position* which the ovary undergoes during life are conspicuous. In the new-born child the organ is relatively long (from 12–18 mm.) and narrow (from 4–5 mm.), triangular on cross section, and lies entirely above the brim of the pelvis, with its long axis transversely placed and its inner pole close to the fundus uteri. During the first two years, owing to the increasing capacity of the pelvis and interabdominal pressure and its attachments to the uterus, it gradually sinks into the pelvic cavity, during this descent the direction of its long axis becoming more vertical. At birth the surface of the ovary is marked with furrows and folds, inequalities that disappear as the organ expands in consequence of the rapid increase in its stroma-tissue during the first year or two. Later the growth of the young ovary is gradual and slow, until the advent of sexual maturity, from the twelfth to the fifteenth year, when the organ undergoes sudden increase and acquires its definite form and size. Further enlargement, however, usually takes place in women who bear children, until towards the fortieth year. The repeated development and rupture of the Graafian follicles and the formation of the corpora lutea produce irregularity of the surface, which becomes knobbed and scarred and contrasts strongly with the smooth organ of childhood. After the cessation of menstruation, about the forty-fifth year, gradual decrease (involution) of the ovary follows, until the organ may be reduced to a dense fibrous body of less than half of the original size.

Variations.—Abnormalities in the sexual glands of the female are, for the most part, referrible to developmental deviations. Incompleteness or modification of its descent affect the position of the organ, so that it may retain its original suprapelvic position and lie above or upon the psoas magnus muscle; or it may follow the pull of the round ligament (the homologue of the genito-inguinal ligament of the male, page 2006) and pass partly or entirely through the inguinal canal into the labium majus. Variations of position in the adult are commonly associated with diseased conditions of the peritoneum and adjacent organs and are therefore pathological. The adult ovary may present marked deviations from its typical form, sometimes being unusually long, spheroidal, flattened, triangular, crescentic, or irregular.

Supernumerary ovaries, varying in size from a hempseed to a small hazelnut, are not infrequent, occurring in from over 2 (Beigel) to 4 (Rieffel) per cent. Their usual situation is along the white line marking the transition of the peritoneum into the germinal epithelium. Isolation of a portion of the ovarian anlage, often probably by a peritoneal band (Nagel), is responsible for these bodies, which consist of normal follicle-bearing ovarian tissue.

PRACTICAL CONSIDERATIONS: THE OVARY.

Since the ovaries project below the Fallopian tubes from the posterior surface of the broad ligaments, in seeking for them in abdominal operations the hand should be passed outward from the posterior surface of the uterus along the broad ligament, on each side.

In its usual position the long axis of the ovary is approximately vertical, its external surface lying against the pelvic wall close to the obturator vessels and nerve. The ureter and uterine artery lie behind and below it.

Prolapse of the ovary occurs most frequently as the result of subinvolution after labor. If involution is in any way arrested or rendered incomplete, the conditions favorable for prolapse of the ovary will be present,—increased weight of the ovary and relaxation and lengthening of its attachments.

The left ovary is more frequently prolapsed than the right, because it normally becomes more enlarged during pregnancy, and therefore suffers more from subinvolution, and because the arrangement of the veins on the left side is such that venous congestion is very liable to occur (Penrose). An analogous anatomical condition exists to that which, in the male, favors left-sided varicocele, the left ovarian vein emptying into the renal vein at a right angle, while the right ovarian vein empties into the vena cava at an acute angle (page 1961).

In complete prolapse the organ lies in Douglas's pouch between the rectum and the posterior vaginal wall. There is apt to be pain on walking, because the ovary is then compressed between the cervix and the sacrum, and on coitus or defecation,

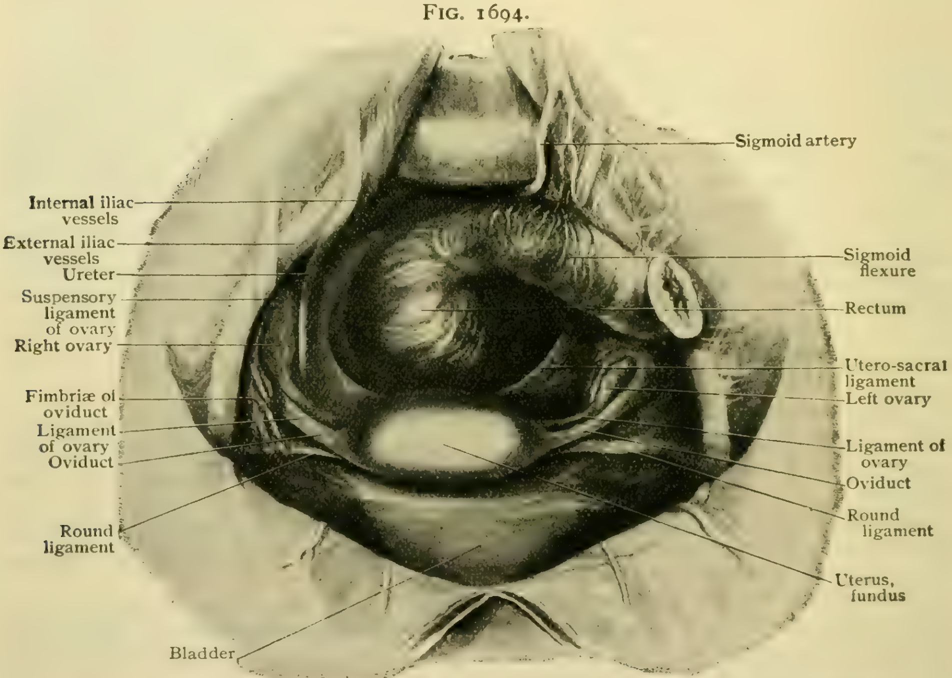
because of direct trauma. The pain is often nauseating and may be felt in the breast on the same side.

In spite of its small size the ovary gives origin to a great variety of tumors and cysts which may grow to enormous proportions, filling and distending the abdomen. As they grow they at first crowd the uterus and other pelvic structures towards the opposite side; later they ascend into the abdomen, drawing the attached structures upward with them in their pedicles. The *pedicle* is the base of attachment, and consists of the same anatomical structures as those by which the ovary is normally attached. The relations of the structures making up the pedicle to one another will vary greatly according to the manner in which the tumor grows. This relationship should be studied carefully to establish a correct diagnosis as to the origin of the tumor. The anatomical structures involved in the pedicle are the mesovarium, mesosalpinx, Fallopian tube, and broad ligament.

THE FALLOPIAN TUBES.

The Fallopian tube (**tuba uterinae**) or *oviduct* is in principle the excretory canal of the sexual gland, the ovary, since it conveys the ova liberated from the Graafian follicles to the uterus, into which it opens. The relation between the ovary and its duct, however, is exceptional in that these organs are not continuous, but only in apposition, the ova liberated from the ovary finding their way into the expanded end of

FIG. 1694.



Pelvic organs of young woman, viewed from above and in front; hardened *in situ* and undisturbed. Fimbriated extremity of right oviduct lay in position shown and not in relation with ovary.

the oviduct. This canal, one on each side of the body, lies within the free margin of the upper division of the broad ligament, known as the *mesosalpinx*, and extends from the uterus medially to the ovary laterally, in relation to the inner surface of which it ends after numerous windings.

The entire length of the tube is about 11.5 cm. (4½ in.), although variations from 6–20 cm. (2⅜–7⅞ in.) have been observed. Emerging from the lateral angle of the fundus uteri, in the immediate vicinity and just above the uterine attachments of the utero-ovarian and round ligaments, the first part of the tube is narrow and

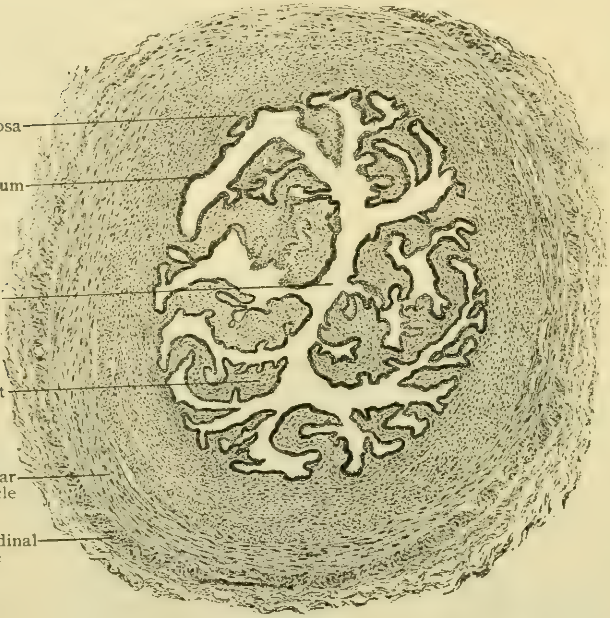
comparatively straight and constitutes the *isthmus* (**isthmus tubae uterinae**), about 3.5 cm. ($1\frac{3}{8}$ in.) in length and from 3–4 mm. in diameter. Throughout the succeeding 8 cm. ($3\frac{1}{8}$ in.) of the tube, known as the *ampulla* (**ampulla tubae uterinae**), the diameter gradually increases (from 6–8 mm.) until the canal suddenly expands into the terminal trumpet-shaped *infundibulum*. The margins of the latter are prolonged and slit up into long, irregular processes, the *fimbriæ*, from 10–15 mm. in length, the resulting *fimbriated extremity* of the tube resembling, when examined in fluid, an expanded sea-anemone (Nagel). One of the fimbriæ (**fimbria ovarica**) is usually longer than the others, attached to the free border of the mesosalpinx and stretches towards the ovary, the tubal pole of which it often, but by no means always, reaches. The *lumen* of the oviduct varies greatly at different points. Beginning at the lateral angle of the uterine cavity as a minute, inconspicuous opening (**ostium uterinum tubae**), commonly obscured by mucus and about 1 mm. in diameter, the canal traverses the uterine wall (**pars uterina**) and gains in size and longitudinal folds, so that on cross-section the isthmus presents a stellate lumen. Within the ampulla the plications of the mucous membrane become progressively more marked, appearing in transverse sections as a complex figure of primary and secondary folds (Fig. 1695) that greatly encroach upon the calibre of the tube. The folds are continued into the infundibulum and onto the inner side of the fimbriæ. The outer or ovarian end of the oviduct opens directly into the peritoneal cavity by a small aperture (**ostium abdominale tubae**), 2 mm. or less in diameter, that lies at the bottom of the infundibulum and is produced by local contraction of the muscular tissue of the wall of the tube, a special sphincter, however, not being demonstrable. The mucous lining of the oviduct is continued from the infundibulum onto the fimbriæ, the line of transition into the peritoneum following the bases and outer sides of the fringes. The exceptional relation of the tubal lining to the serous membrane, this being the only place in the body where a mucous tract opening onto the exterior communicates with a closed serous sac, is referrible to the similar original relation of the embryonal Müllerian duct from which the Fallopian tube is directly derived (page 2038).

Course and Relations.—Since each Fallopian tube occupies the free border of the broad ligament, changes in the position of the uterus affect the course of the oviduct. From the upper angle of the uterus the tube may, therefore, first pass outward towards the ovary in a strictly transverse direction, or describe a gentle forward or backward curve, depending upon the position of the fundus uteri, this part of the tube, however, never being tortuous. On gaining the uterine or lower pole of the ovary, it there bends upward and winds obliquely, from below upward and backward, across the median surface of the ovary, close to the anterior border and tubal pole, to the convex posterior margin, where the tube bends sharply downward, its fimbriated end being in relation with the lower and back part of the median surface. When in its usual position, the ovary is, thus, partly covered not only by the tortuous oviduct itself, but also necessarily by the mesosalpinx in which the tube lies, so that when viewed from above the ovary is often entirely hidden by the Fallopian tube and the attached portion of the broad ligament. In consequence of this arrangement, the ovary is partly surrounded by a hood of serous membrane and lies within a pocket, known as the *bursa ovarii*, which may facilitate the entrance of the liberated ova into the Fallopian tube. In its course from the uterus to the ovary the oviduct lies in front of and generally parallel with the utero-ovarian ligament and is overlaid by the coils of the small intestine. As the tube ascends and arches over the ovary, the intestinal coils cover its medial surface, the sigmoid colon also occasionally being in relation on the left side. In formalin-hardened subjects, with otherwise normal pelvic contents, we have so often found the termination of the Fallopian tube lying away from the ovary, that Merkel's suggestion, that the assumed constant close relation between the fimbriated extremity and the ovary may sometimes, at least temporarily, be wanting during life, seems well founded.

Structure.—The wall proper of the Fallopian tube, consisting of the mucous and muscular coats, lies embedded within the loose connective tissue of the broad ligament (*tunica adventitia*) surrounded by the peritoneum, which completely invests the tube with the exception of the narrow interval through which the tubal vessels and nerves pass. The wall is thickest and firmest in the isthmus, less so in the

ampulla, and thinnest and most relaxed in the infundibulum and fimbriæ. The mucous membrane is thrown into longitudinal folds, which increase from 5–15 low ridges in the commencement of the isthmus to double the number in the ampulla, where they attain a much greater height as well as complexity of arrangement, the main folds being supplemented by secondary and tertiary ones, so that in transverse section the lumen appears almost occluded by branching villus-like projections. The surface of the mucosa is covered with a single layer of columnar epithelium (from .015–.020 mm. in height) provided with cilia that produce a current directed from the infundibulum towards the uterus, and thus, while facilitating the progress of the ova along the tube, retard the ascent of the spermatozoa. The elaborate plications and recesses within the outer part of the ampulla favor the temporary retention of the sexual cells and thereby promote the chance of their meeting, fertilization usually taking place within this part of the tube. The vascular connective-tissue stroma of the folds, which in the chief plications may reach a thickness of .2 mm., within the accessory folds is reduced to a narrow interepithelial layer in places measuring less than the height of the covering cells. The tunica propria of the mucosa is directly continuous with the intermuscular connective tissue, and, with the exception of a few bundles prolonged into the deepest part of the mucous membrane, does not contain muscular tissue.

FIG. 1695.



Cross-section of oviduct near outer end of ampulla. × 35

The *muscular coat*, most robust towards the uterus and thinnest at the infundibulum (therefore the reverse of the arrangement of the mucosa), includes an inner circular and an outer longitudinal layer of involuntary muscle. At the isthmus, where the firmness of the tubal wall depends chiefly upon the muscular coat, the circular layer is the thicker (from .5–1 mm.) and the longitudinal one represented by an incomplete stratum of muscle-bundles. Towards the infundibulum, on the contrary, the longitudinal layer is better developed, the circular-muscle being reduced to .2 mm. or less in thickness. The surrounding fibrous tissue, sometimes regarded as a distinct coat of the tube (*tunica adventitia*), and the outer serous investment are only the usual connective tissue and peritoneal constituents of the broad ligament, and, therefore, call for no further description in connection with the oviduct. As evidenced in pathological conditions, and especially in tubal pregnancy, the wall of the oviduct is capable of distention to a remarkable degree.

Vessels.—The *arteries* supplying the oviduct are derived from the tubal branches of the uterine and ovarian vessels. The branch from the uterine artery (*ramus tubarius a. uterinæ*) passes in front of the utero-ovarian ligament to the median end of the oviduct, along the under side of which it courses outward until it meets the tubal branch from the ovarian artery. The latter (*ramus tubarius a. ovaricæ*) passes within the mesosalpinx, in front of the ovarian fimbria, towards the outer part of the ampulla, distributing branches to the fimbriated extremity, and mesially joins the tubal branch from the uterine. From the anastomotic branch so

formed numerous twigs are given off to the wall of the Fallopian tube and to the mesosalpinx. Those distributed to the oviduct gain the canal along its nonperitoneal tract between the peritoneal reflection and, piercing the wall, break up into capillary net-works within the muscular and mucous coats. The *veins*, which begin within the walls of the tube, especially between the muscular layers, and as a subserous net-work, follow the arteries and become tributary to both the uterine and ovarian trunks.

The *lymphatics*, after emerging from the wall of the tube, form three or four stems that accompany the blood-vessels and pass in front of the attached border of the ovary. For the most part they follow the ovarian lymphatics through the suspensory ligament to become finally tributary to the lumbar lymph-nodes surrounding the aorta. It is probable that some of the lymphatics of the tube communicate with those of the fundus uteri (Poirier, Bruhns).

The **nerves** supplying the Fallopian tube, numerous and chiefly sympathetic fibres, follow the arteries and, therefore, reach the oviduct from both the ovarian and the uterine plexus. Within the subserous tissue they form a *peritubal plexus* from which twigs penetrate the wall of the canal and are distributed principally to the muscular tissue, some filaments taking part in the production of a *subepithelial plexus* within the mucous membrane (Jacques).

Development and Changes.—The early development of the oviducts is directly associated with that of the embryonal Müllerian ducts (page 2038), the unfused portions of which the tubes represent. The margin of the abdominal opening (the persistent original evagination from the primary body-cavity or cœlom) is at first cushion-like, but soon exhibits indentations which, by the fifth fœtal month, develop into distinct fimbriæ. At birth, while smaller, the latter possess their characteristic appearance and are lined by ciliated columnar epithelium that covers the plications of the tube. The upper (outer) segment of the oviduct participates in the migration incident to the descent of the ovary, lying for a time within the abdomen above the pelvic brim. In contrast to the ovary, the tube early acquires its definite form, in the new-born child presenting its chief characteristics, although it is more twisted than later and the fimbriæ are still small; the plication of the mucosa, however, is almost fully developed. During childhood, beginning at the uterine end, the tube becomes less tortuous and the fimbriated extremity assumes its definite proportions. In advanced age, the oviduct suffers atrophy, losing its former tortuosity, the infundibulum becoming flaccid and the fimbriæ shrivelled. Owing to the atrophy of the muscle its wall becomes thinner; the ciliated columnar epithelium is replaced by cuboidal cells, the lumen narrows and in places may disappear in consequence of the adhesion of the mucous folds.

Variations.—Apart from anomalous situation depending upon malposition of the uterus and ovary, in which the tube of necessity shares, the variations of the oviduct usually depend upon developmental faults traceable to imperfect or aberrant formation of the Müllerian ducts. Retention of the fœtal tortuosity, stunted development or entire absence may affect one or both tubes. Complete doubling of the oviducts may occur in association with supernumerary ovaries. Occasionally partial duplication of the tube is observed, consisting of a short canal ending in a diminutive fimbriated extremity in the vicinity of the infundibulum. Such *accessory tubes* are to be referred probably to a repetition of the invagination that normally produces the infundibulum (Nagel). Quite frequently the oviduct is beset with from one to three fringed *accessory openings* that may lie close to the fimbriated end, or at a distance from the latter along the tube. The explanation of these apertures is uncertain, although it seems most probable that they result from aberrant development of the Müllerian duct, rather than as secondary perforations of the tube and prolapse of its mucosa, as held by Nagel and others.

PRACTICAL CONSIDERATIONS: THE FALLOPIAN TUBES.

The function of the Fallopian tube is to transmit the ovum from the ovary to the uterus, the ciliated epithelium of the tube favoring movement in that direction. An impregnated ovum may adhere to the wall of the tube, giving rise to an *ectopic gestation* (tubal pregnancy). Such pregnancy may occur in the ampulla,—the most usual place,—in the infundibulum (tubo-ovarian pregnancy), or in the intra-mural portion of the tube,—*i.e.*, that part traversing the wall of the uterus.

The chief causes of tubal pregnancy are pathological or abnormal conditions of the tube. The more important of these are: (*a*) congenital, such as exaggerated convolutions, diverticula, and atresias; (*b*) sagging and attachments by adhesions distorting the tube; (*c*) pressure from surrounding structures; (*d*) thickening of the tubal walls, interfering with peristalsis; and (*e*) destruction of the cilia or narrowing of the tube following salpingitis. Complete occlusion of the tubes of both sides would result in sterility.

The great danger of ectopic gestation is that of hemorrhage following *rupture* of the tube by the growing fœtus. This will occur some time prior to the fourth month, and may be *intraperitoneal,—i.e.*, directly into the peritoneal cavity; or *extraperitoneal,—i.e.*, downward, cleaving the layers of the broad ligament, and finally rupturing the tube within the layers of the ligament; or, in case the pregnancy is "interstitial," the rupture may be *intrauterine*. The intraperitoneal rupture usually takes place before the seventh week; the extraperitoneal usually from the seventh to the twelfth week. If the fœtus should survive the primary rupture in the extraperitoneal variety, secondary rupture into the general peritoneal cavity may occur later, and the ovum may go on to full term within the abdominal cavity.

The Fallopian tube offers a passageway in the opposite direction for the entrance of *infections*, especially gonorrhœal, from the vagina and uterus into the peritoneal cavity. When inflammation involves the tube, it is followed soon by a closure of the fimbriated extremity, the fimbriæ adhering to each other, to the ovary, or to some adjacent peritoneal surface. Later the uterine end of the tube also closes, and the pus which results from the infection now accumulates within the tube (*pyosalpinx*) and may greatly distend it. If the infection is gonorrhœal, such a pus-tube without rupture is frequently unaccompanied by acute symptoms. Slight ruptures with leakage into the peritoneal cavity followed by sharp attacks of localized pelvic peritonitis often occur. A large rupture may give rise to a diffuse septic peritonitis, although the danger of this result in a case of chronic pyosalpinx, even if of enormous size, is far less than after acute gangrene of the appendix with escape of a relatively minute portion of its contents. In the former case a certain degree of immunity has probably been established during the slow formation of the pyosalpinx (Binnie); and moreover, in many such cases (61 per cent., Penrose) the contained pus has become sterile.

When the inflammation is of a mild grade the accumulation may be of a serous character (*hydrosalpinx*), and may become so large as to reach half-way to the umbilicus. If hemorrhage occurs into the tube it is called an *hæmatosalpinx*.

The proximity of the right Fallopian tube to the appendix should be recalled, as salpingitis on that side has not infrequently been mistaken for appendicitis, and *vice versa*. The right ovary is often connected with the meso-appendix by a fold of peritoneum,—the appendiculo-ovarian ligament; and it is stated that the fact that this fold often contains a small artery which gives an additional blood-supply to the appendix helps to account for the relative infrequency of appendicitis in females.

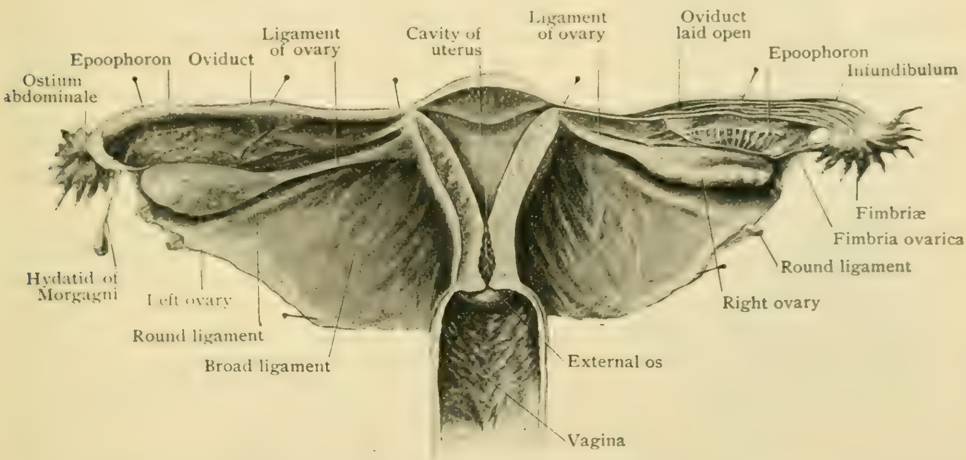
RUDIMENTARY ORGANS REPRESENTING FŒTAL REMAINS.

The development of the reproductive organs (page 2042) emphasizes the fact that whereas, in the male, the Wolffian body and its duct play a very important rôle in the production of the excretory canals for the sexual gland, the Müllerian duct remains rudimentary; in the female, the converse is true, the Müllerian ducts forming the excretory canals—the tubes, the uterus, and the vagina—while the Wolffian structures are secondary in importance and give rise to only rudimentary and functionless organs, situated chiefly in the vicinity of the ovary and Fallopian tube between the layers of the broad ligament. These fœtal remains include the *epoophoron*, *Gartner's duct*, the *paroophoron*, and the *vesicular appendages*, which may be appropriately described in this place.

The Epoophoron.—This rudimentary organ, *parovarium* or *organ of Rosenmüller*, lies between the layers of the broad ligament (mesosalpinx) in front of the ovarian vessels, in the area bounded by the ampulla of the oviduct, the ovarian fimbria and the tubal pole of the ovary. It is quite flat, triangular, or

trapezoidal in outline, and measures from 2–2.5 cm. in length and about 1.75 cm. in width. It consists of from 8–20 narrow wavy canals, which, beginning with closed and slightly expanded ends, diverge from the vicinity of the hilum of the ovary and join, almost at right angles, a common chief duct that lies close and parallel to the oviduct and bears to the smaller tubules the relation of the back of a comb to its teeth. The transverse tubules (**ductuli transversi**), the remains of the sexual tubules of the Wolffian body, may extend as far as the hilum, or, as in the young child, even penetrate into the medulla of the ovary and be continuous with the rudimentary medullary tubes therein found, since the latter, as well as the transverse tubules themselves, are vestiges of the same embryonic structures. The common longitudinal canal (**ductus epoophori longitudinalis**), closed at both ends, is a persistent portion of the Wolffian duct. From its embryological relations it is evident that the epoophoron is homologous with the epididymis (the transverse tubules corresponding to the ductuli efferentes and the coni vasculosi, and the longitudinal duct to the canal of the epididymis), since both are direct derivations from the Wolffian tubules and duct. In the erect posture, when in its normal position within the mesosalpinx, the longitudinal duct is approximately vertical and lies parallel with the Fallopian

FIG. 1696.



Broad ligaments, viewed from behind, have been stretched out and pinned, the posterior wall of uterus and vagina removed and right oviduct laid open. Ovaries do not occupy their normal position, their long axes here being horizontal instead of approximately vertical.

tube, while the transverse tubules are horizontally disposed. The chief duct may be interrupted and connected with the secondary tubules in groups, or, on the other hand, it may be prolonged as Gartner's duct (page 2043) far beyond its usual length. In the child, the transverse tubules, from .3–.4 mm. in diameter, usually possess a lumen throughout their entire length, but later in life the minute canals may undergo partial or complete occlusion and may be the seat of cystic dilatations. The walls of the tubules and duct consist of a fibrous coat, which sometimes contains bundles of involuntary muscle, lined by a single layer of epithelial cells that vary in form from low cuboid to columnar, and in places, or occasionally in the adult and frequently in the child, bear cilia. The epoophoron is most satisfactorily demonstrated by holding the stretched mesosalpinx against the light ; it is more conspicuous in the broad ligament of the young child on account of its development and the greater transparency of the overlying tissues. In common with the sexual organs, the epoophoron increases during the years leading to sexual maturity and atrophies in advanced age. During pregnancy it is said to be unusually vascular (Merkel).

Gartner's duct results from the more or less extensive persistence of portions of the Wolffian duct that usually disappear by the end of fœtal life, and is, therefore, a continuation, direct or interrupted, of the longitudinal canal of the epoophoron. Although by no means constant and often represented by only a short atrophic

segment, the duct is present in about twenty per cent. (Merkel) of adult subjects, in children being relatively better developed. When complete, as it exceptionally is, the duct continues from the epoophoron along the Fallopian tube to the fundus of the uterus, then descends within the lateral border of the uterus, between the vessels, and sooner or later (usually in the lower part of the body) enters the uterine muscle. As it traverses the cervix, the duct becomes more and more medially placed until, in the supravaginal segment, it approaches the mucosa. The duct then assumes a more lateral course, and in the vagina descends within the muscular coat, at first along the side and lower more on the anterior wall, to end blindly in the vicinity of the hymen (R. Meyer). Such complete persistence is, however, very unusual, Gartner's duct being most frequently represented in the lower part of the body and the upper part of the cervix, less often in the cervical segment alone (Maudach). The canal is lined by a single layer of columnar epithelium and beset with lateral diverticula, uncertain in number and form, which in the lower part of the duct are often short-branched tubules that resemble glands. Accumulations of secretion within the tubules or the duct may lead to the production of cysts.

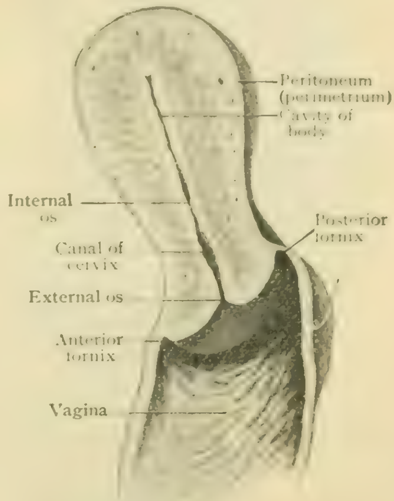
The Paroophoron.—Under this name Waldeyer described an inconspicuous rudimentary organ, distinct at birth, but usually disappearing, and only exceptionally retained after the second year, that lies between the layers of the mesosalpinx medially to the epoophoron and, therefore, nearer the uterus. It consists of a small, flat, irregularly round group of blind canals, which represent the remains of Wolffian tubules. The accuracy of Waldeyer's assumption that this organ is homologous with the paradidymis (page 1950) has been challenged by later investigators (Aschoff, R. Meyer), who have discovered similar groups of rudimentary tubules within the lateral part of the mesosalpinx near the division of the ovarian artery, in a position corresponding to that of the paradidymis. It is to this group, therefore, that the term, paroophoron, may be applied with greater propriety, although there can be little doubt that both sets of tubules are deviations from those of the Wolffian body. The tubules are blind, lined with columnar epithelium, and in places resemble the tortuous canals of the Wolffian body. Apart from their interesting morphological relations, they may become of importance as the seat of cysts.

Vesicular Appendages.—Under this heading are included the little vesicles or hydatids (appendices vesiculosi) attached to the broad ligament by longer or shorter pedicles. These structures present two general groups, the first including the conspicuous long-stalked hydatids of Morgagni, and the second the smaller vesicles, varying in form and size, connected by short stems. The *hydatid of Morgagni*, present on one or both sides in fifty per cent. or over of all female subjects, is a spherical or pyriform thin-walled sac, that contains a clear fluid, and usually measures from 4–8 mm. in diameter, but sometimes much more, and is attached by a slender stalk (from 1.5–4 cm. in length) to the anterior surface of the broad ligament. Traced towards the latter, the stalk crosses the ovarian or other fimbriæ without being attached and sinks into the mesosalpinx about 1 cm. from its free border, from which point it may be followed through the broad ligament to the upper end of the main or longitudinal duct of the epoophoron, as the continuation of which it may be identified (Watson). In structure the hydatid consists of a fibrous coat, lined by a layer of columnar epithelium and covered externally with a delicate prolongation of the peritoneum. The *smaller vesicles*, present in about twenty per cent. (Rossa), often number two or three on each side, and are attached to the anterior surface of the mesosalpinx, usually over the epoophoron. They are found at birth and even in the fœtus, as well as later in life, in advanced age undergoing atrophy The origin and morphological significance of the vesicular appendages have occasioned much discussion, but it may be accepted as established that the chief hydatid of Morgagni is derived from the upper end of the Wolffian (pronephric) duct, and is, therefore, the equivalent of the stalked appendage of the epididymis (page 1949). The smaller vesicles probably owe their origin to the distention and elongation of the transverse canals of the epoophoron (Rossa), and, hence, are derivatives of the Wolffian tubules.

THE UTERUS.

The uterus, or womb, is a hollow muscular organ, receiving the Fallopian tubes above and opening into the upper part of the vagina below, in which the fertilized ovum is retained and undergoes development, and from which the resulting fœtus is expelled at the completion of pregnancy. Its lower segment is embedded within the pelvic floor between the bladder and the rectum, while its upper and larger end is free and movable and rests upon the superior surface of the bladder (Fig. 1700). Before undergoing the profound changes incident to pregnancy, the uterus, pear-shaped in its general form, measures about 7 cm. ($2\frac{3}{4}$ in.) in length, of which the lower 2.5 cm. (1 in.) constitutes the cylindrical neck or *cervix* (**cervix uteri**), and the remainder the *body* (**corpus uteri**). Its greatest breadth is about 4 cm. ($1\frac{5}{8}$ in.) and its thickness about 2.5 cm. (1 in.). In women who have borne children, the uterus seldom quite returns to its virgin size, but shows a permanent increase of about 1 cm. in its various dimensions, except in the cervix, which is relatively shorter than before. The convex upper extremity of the organ, above the level of the entrance of the Fallopian tubes, is known as the *fundus* (**fundus uteri**), which in front and behind passes into the anterior and posterior surfaces and at the sides into the lateral borders (**margo laterales**). Of the two surfaces, the anterior (**facies vesicalis**) is the more flattened and less convex and only partially covered with peritoneum, while the more rounded and projecting posterior surface (**facies intestinalis**) is almost completely invested with peritoneum. The lower end of the cylindrical cervix, flattened somewhat from before backward and slightly tapering downward, is divided by the attachment of the surrounding vaginal wall, which it seemingly pierces, into a free lower segment (**portio vaginalis**), that projects into the vault of the vagina, and an upper one above the ring of attachment (**portio supravaginalis**). Below, the vaginal segment of the cervix terminates in thick, rounded, and prominent lips that bound a sunken opening, the *external os* (**orificium externum uteri**) that marks the lower limit of the cervical canal and is directed towards the posterior vaginal wall. Owing to the horizontal position of the cervix, the thicker *anterior lip* (**labium anterius cervicis**) is shorter and somewhat lower than the overhanging *posterior lip* (**labium posterius cervicis**).

FIG. 1697.



Uterus laid open by sagittal section, showing cavity and relations of labia to vagina.

The weight of the virgin uterus varies between forty and fifty grammes ($1\frac{1}{3}$–$1\frac{3}{4}$ oz.), that of the organ after pregnancy being about twenty grammes (.7 oz.) more.

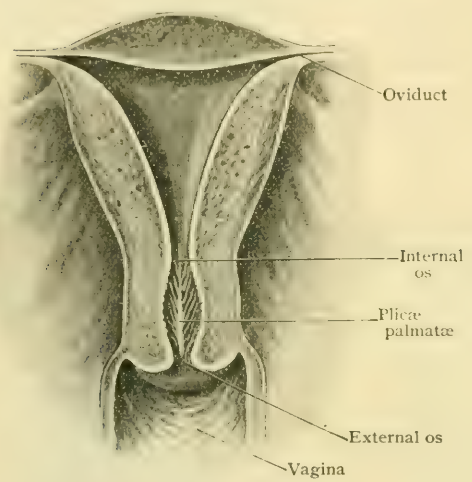
The *cavity* of the uterus is small in comparison with the size of the organ and the thickness of its walls, and differs in form according to the plane of section. In sagittal section, it is little more than a narrow cleft separating the opposed anterior and posterior walls, and measures about 6 cm. ($2\frac{3}{8}$ in.), of which 2.5 cm. (1 in.) belongs to the cervix. In frontal section, the cavity of the body is triangular in outline (Fig. 1698), the apex being below, where the upper end of the cavity of the cervix passes into that of the body, and the base above, between the tubal orifices which mark the lateral angles. The sides of the triangle are not straight but convex, owing to the inward curve of the thick projecting uterine walls. The greatest transverse width of the cavity of the body, just below the tubal openings, is about 2.5 cm.

The *canal of the cervix* (**canalis cervicis uteri**), as the lower segment of the uterine cavity is called, is fusiform in longitudinal sections, being widest midway between the external os below and the somewhat smaller and more circular internal os (**orificium internum uteri**) above, where the contracted lumen of the virgin uterus expands into

the cavity of the body. In cross-section the canal appears as a markedly compressed oval. The position of the internal os corresponds with the slight external constriction (**isthmus uteri**) that uncertainly marks the neck from the body of the uterus. In contrast to the smooth mucous surface of the body, that of the anterior and posterior walls of the cervical canal is marked by conspicuous ridges (**plicae palmatae**)—the *arbor vitæ uterinæ* of the older writers—consisting of a chief median longitudinal fold from which numerous secondary rugæ diverge upward and outward on each wall.

Attachments and Peritoneal Relations.—In addition to the Fallopian tubes that embryologically are direct continuations of the component Müllerian ducts by the fusion of which the uterus is formed, the uterus is connected with the ovaries, the abdominal wall, the lateral and posterior walls and the floor of the pelvis, the vagina, the bladder, and the rectum by fibro-elastic tissue, muscular bands, and peritoneal folds. Most of these attachments, or so-called ligaments, however, have little influence in supporting the uterus, but, owing to the intimate connection of the cervix with the vagina, and thus with the pelvic floor, and with the sacrum by fibro-muscular bands, the lower segment enjoys a relatively fixed position; the body, on the contrary, being freely movable.

FIG. 1698.



Uterus laid open by frontal section, showing form of cavity of body and cervix.

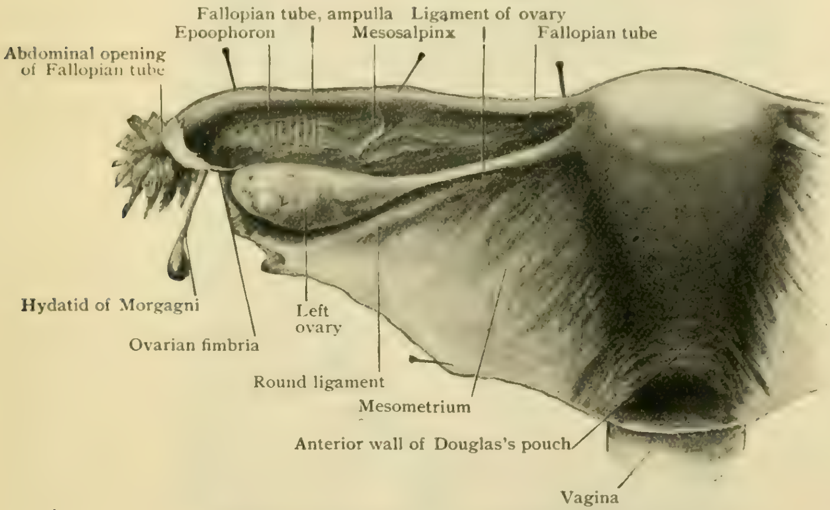
The Broad Ligament.—With the exception of a narrow strip along the sides between the layers of the broad ligaments, the body of the uterus is completely invested by peritoneum. The cervix, on the contrary, possesses a serous covering only behind and at the sides above the attachment of the vagina. From each lateral border of the uterus this serous investment is reflected to the pelvic wall and floor as a conspicuous transverse duplicature of peritoneum, the *broad ligament* (**ligamentum latum**), that passes across the pelvis and encloses between its layers the round and ovarian ligaments, the Fallopian tube, the epoophoron and the paroophoron, together with the associated vessels and nerves. Although enclosed by a peritoneal duplicature continued from its posterior surface, the ovary is attached to, rather than lies within, the broad ligament. When detached from the pelvic wall and floor and spread out (Fig. 1699), the broad ligament is wing-like in form and has four borders, of which the median or uterine is vertical, the upper or tubal is horizontal, longest, and free, the lateral short and approximately vertical to correspond with the plane of the pelvic wall, and the lower sloping downward and inward in agreement with the direction of the pelvic floor. Within the body, the plane of the median portion of the fold depends upon the position of the uterus, in the erect posture usually extending more or less horizontally, so that the posterior surface presents upward and backward, and the anterior downward and forward; when the uterus assumes an upright position, the fold likewise becomes erect. On nearing its lateral attachment, the upper border of the broad ligament becomes not only more vertical, but also parallel with the pelvic wall in consequence of the support afforded by the suspensory ligament of the ovary. From their attachment to the pelvic walls and floor the two serous layers of the broad ligament pass in opposite directions and are continuous with the general peritoneal lining of the pelvis. Along the pelvic floor their divergence leaves a non-peritoneal interval through which the vessels and nerves and the ureter gain the side of the uterus.

The free border of the broad ligament is occupied by the Fallopian tube, the course of which it follows as far as the outer end of the infundibulum, and thence passes to the pelvic wall to become continuous with the suspensory ligament of the

ovary. As the tube crosses the medial surface of the latter organ the broad ligament is drawn over it, so that the ovary lies partly within a peritoneal pocket, the *bursa ovarii*. The anterior border of the ovary is attached to the posterior surface of the broad ligament by a short fold, the *mesovarium*, that encloses the hilum and is continued into the modified serous investment that covers the sexual gland. The utero-ovarian ligament and the attached border of the ovary unequally divide the broad ligament into an upper narrow triangular portion, the *mesosalpinx*, that encloses the tube, and a lower broad part, the *mesometrium*, that passes medially to the sides of the uterus and becomes continuous with the *perimetrium*, as the serous investment of that organ is termed. Within the mesosalpinx the connective tissue filling the interval between the two serous layers of the broad ligament is very scanty, but within the mesometrium this tissue increases to a considerable stratum and contains numerous strands of smooth muscle prolonged from the uterus. Surrounding the uterus, it is known as the *parametrium*, and along the attached borders of the ligament laterally, and below, becomes continuous with the general subserous layer of the pelvis.

The Round Ligament.—In addition to the Fallopian tube and the ligament of the ovary, already described (page 1987), a third band, the round ligament (**ligamentum teres**), passes on each side from the upper lateral angle of the uterus. This structure, a flattened cord from 12–14 cm. (4¾–5½ in.) long and about .5 cm. thick, springs from the side of the uterus, in front and below the entrance of the oviduct, and extends (Fig. 1684) between the layers of the broad ligament horizontally outward to the lateral pelvic wall, which it reaches near the floor. Thence it continues its course beneath the peritoneum forward and slightly upward, crosses the obliterated hypogastric artery, the pelvic brim, and the external iliac vessels, and, hooking around the outer side of the deep epigastric artery, gains the internal abdominal ring. Passing through the latter and traversing the entire length of the inguinal canal, the round ligament emerges from the external abdominal ring and ends by breaking up into a number of diverging fibrous bands that become mostly lost in the subcutaneous tissue of the labium majus, while a few find attachment to the pubic spine. In its median third the round ligament contains robust bundles of involuntary muscle prolonged from the superficial layers of the uterus, but beyond the muscular tissue disappears, and in its lower part the band consists entirely of fibro-elastic tissue. During its passage through the inguinal canal, the ligamentum teres is accompanied, along its upper border, by small, short bundles of striped muscle

FIG. 1699.

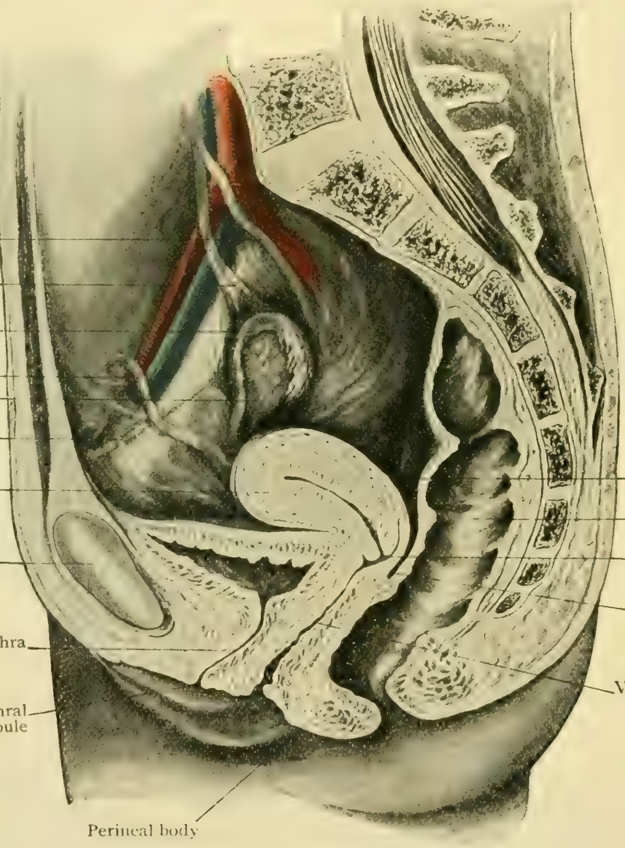


Uterus and appendages seen from behind; broad ligament and oviduct have been stretched out to show mesosalpinx.

derived from the internal oblique and transversalis, which represent a feebly developed cremaster muscle. After gaining the pelvic wall, the round ligament pursues a course very similar to that of the vas deferens; morphologically, it corresponds to the genito-inguinal ligament (page 2040). In the fœtus the round ligament is preceded by a small peritoneal diverticulum representing the larger processus vaginalis peritonei in the male; usually this disappears, but may persist as a distinct serous pouch, *the canal of Nuck*, that accompanies the round ligament for a short distance within the inguinal canal. In exceptional cases it may extend throughout the entire length of the canal into the labium majus.

The **peritoneal relations** of the two surfaces of the uterus (Fig. 1700) are different, the anterior surface being covered with serous membrane only as far as the

FIG. 1700.



Sagittal section of pelvis of female.

junction of the body and cervix, from which line the peritoneum passes on to the bladder as the *utero-vesical fold* and lines the shallow *utero-vesical pouch* (**excavatio vesicouterina**). Below the reflection of the peritoneum and as far as its attachment to the vagina, the anterior surface of the cervix is connected by areolar tissue with the adjacent posterior wall of the bladder. As far as the attachment of the vaginal wall, the posterior surface of the uterus is covered with peritoneum, which then continues downward for about 2.5 cm. over the upper part of the back wall of the vagina before being reflected onto the rectum as the *vagino-rectal fold*. The latter forms the bottom of the deep serous *pouch of Douglas* (**excavatio rectouterina**) that lies between the uterus in front and the rectum behind. The lateral boundaries of the opening into this pouch are formed by the two crescentic *utero-rectal folds* (**plicae rectouterina**) that curve from the hind surface of the cervix backward to the posterior pelvic wall at the

sides of the rectum. Between the layers of these folds robust bundles of fibrous and smooth muscular tissue extend from the uterus to be inserted partly in the rectum, there constituting the *utero-rectal muscle*, and partly into the front of the sacrum as the *utero-sacral ligament*. The latter structure contributes efficient aid in supporting the cervical segment of the uterus, which is thus enabled to maintain its position independently, to a certain degree, of that of the body.

Position and Relations.—The attachment of the cervix to the vaginal walls and utero-sacral ligaments give to the lower uterine segment a more definite position than that enjoyed by the body, which, being little restrained by its lateral attachments, is especially affected by the condition of the bladder and rectum. When these organs are but slightly distended, the uterus normally, in the erect posture, lies tilted forward (anteverted), with the body resting upon the upper vesical surface. Since, under these conditions, the cervix is comparatively fixed and directed backward and the body more or less bent forward (antiflexed), the uterine axis exhibits a marked flexure at the beginning of the cervical segment. This angle varies continually with the position of the fundus, which, receiving little support from its peritoneal and other attachments, is influenced by the changing condition of the bladder. When the latter is contracted and the uterus strongly anteflexed, the angle is more pronounced than when the upper vesical wall, and consequently the fundus, lies higher. With increasing distention of the bladder the angle gradually disappears and the uterine axis becomes straight; in excessive vesical expansion, associated with an empty rectum, the entire uterus may be tilted backward (retroverted), its axis then corresponding with that of the vagina. When both bladder and rectum are distended, the entire uterus may be pushed up above the level of the symphysis. Usually the fundus does not lie strictly in the mid-line but to one side, probably more frequently to the left (Waldeyer, Merkel). This deflection may also affect the axis of the ovary of the opposite side, which, in consequence of the pull thus exerted, then lies more obliquely than on the side on which the utero-ovarian ligament is relaxed. The anterior surface of the uterus following the changes of the upper vesical wall upon which it lies, the utero-vesical fossa very seldom contains intestinal coils, which, on the contrary, frequently occupy the pouch of Douglas. The posterior (upper) surface of the uterus is overlaid by coils of the small intestine, and may also be in contact with the pelvic and sigmoid colon. Anteriorly, below the reflection of the utero-vesical fold, the lower segment of the uterus is connected with the posterior bladder-wall by loose connective tissue; posteriorly, it is separated from the rectum by the intervening peritoneal pouch of Douglas; laterally, it is crossed by the ureters, which, opposite the middle of the cervix, lie about 2 cm. from the uterine wall. In the erect position, the level of the external os corresponds approximately with that of the upper margin of the symphysis, and in the antero-posterior axis lies slightly behind a frontal plane passing through the ischial spines (Waldeyer).

Structure.—The uterine walls, thickest in the fundus and posterior wall of the body, where they measure from 1–1.5 cm., and somewhat thinner (from 8–9 mm.) at the entrance of the tubes and in the cervix, comprise three coats, the mucous, muscular, and serous. The *mucous coat*, or *endometrium*, of a light reddish color, soft, and friable, and from .5–1 mm. thick, consists of a connective-tissue stroma, loose in texture but rich in cells and resembling the tunica propria of the intestinal mucous, and the surface epithelium. The latter is a single layer of columnar cells, about .028 mm. high, that in their typical condition possess cilia by which a downward current is established towards the external os. It is probable, however, that the cilia are neither always present, nor uniformly distributed, since they are lost during the disturbances incident to menstruation, and are often present only in patches (Gage). The *uterine glands* are simple tubular, or slightly bifurcated, wavy invaginations of the mucosa, usually lined with a single layer of ciliated columnar cells resembling those covering the interior of the uterus. They are distributed at fairly regular intervals and extend the entire thickness of the mucosa, their tortuous, blind extremities in many cases being lodged between the adjacent muscular bundles, since a distinct submucosa is wanting. In the vicinity of the orifices of the Fallopian tubes, the uterine mucosa becomes thinner, the epithelium lower,

and the glands shorter and fewer, until they finally disappear, glands being absent in the tubal mucous membrane.

The *cervical mucosa* differs from that lining the body in being somewhat denser, owing to the greater amount of fibrous tissue within its stroma, and in possessing a taller epithelium, a single layer of columnar cells from .040–.060 mm. in height, and larger mucous glands. The latter (glandulae cervicales uteri), from 1–1.5 mm. long and .5 mm. wide, are branched and often reach with their blind ends between the muscle bundles. The mucus secreted by these glands is peculiar, being clear and exceeding tenacious, and sometimes is seen as a plug protruding from the external os. Not infrequently the orifices of the cervical glands become blocked, which condition results in the production of retention cysts that appear as minute vesicles between the folds of the plicæ palmatæ. These bodies were formerly described as the ovules of Naboth (*ovula Nabothi*). The transition of the cylindrical epithelium of the cervical canal into the squamous cells covering the vaginal portion of the uterus takes place abruptly at the inner border of the external os. At the inner os, where the cervical mucosa passes into that lining the body, the change is so gradual and inconspicuous that no sharp demarcation exists.

FIG. 1701.

Section of endometrium, showing uterine glands cut in various planes. × 40.

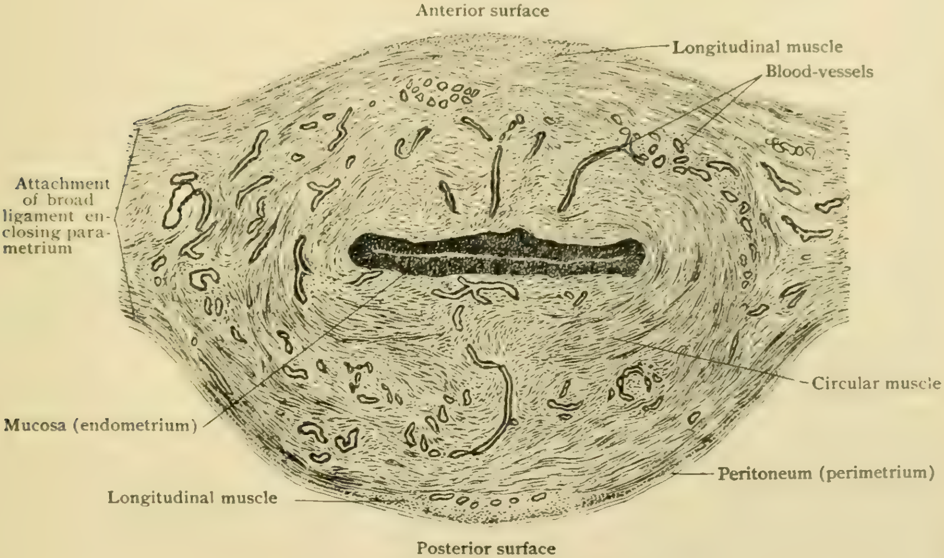
The *muscular coat*, or *myometrium*, although composed of bundles of involuntary muscle arranged with little individual regularity, may be resolved into a robust *inner layer*, in which the bundles possess a general circular disposition, and a thin, imperfect *outer layer* in which their course is for the most part longitudinal. The longitudinal muscle bundles of the feeble outer layer, which is present only over the fundus and body, are continued beyond the uterus onto the tubes and into the broad, round, ovarian and utero-sacral ligaments. The thick inner layer, the chief component of the myometrium, is distinguished by the number and size of the blood-vessels that traverse the intermuscular connective tissue and, hence, is known as the *stratum vasculare* (Kreitzer). The bundles of this layer are confined to the uterus, except below, where they become continuous with the muscle of the vaginal walls. At the three angles of the body, corresponding to the two tubal orifices and the internal os, the disposition of the bundles surrounding these openings suggests the existence of distinct sphincters. In other places the innermost bundles are less regularly disposed and are oblique or even longitudinal. Within the cervix the outer longitudinal layer is unrepresented, the musculature of this segment consisting chiefly of circular and oblique bundles, intermingled with a considerable amount of dense fibrous and elastic tissue that confer upon the cervix greater resistance and hardness. The component fibre-cells of the uterine muscle vary in form, being in some places short and broad

and in others long and spindle form. During pregnancy their usual length (from .040–.060 mm.) may increase tenfold.

The *serous coat*, or *perimetrium*, continuous laterally with the peritoneal investment of the broad ligament, is so closely adherent to the uterine muscle over the fundus and adjacent parts of the anterior and posterior surfaces that it is removed with difficulty. Lower, the presence of the intervening loose connective tissue (*parametrium*) renders the attachment less intimate.

Vessels.—The *arteries* supplying the uterus are the two uterine, each a branch of the internal iliac that accompanies the ureter along the pelvic wall, behind and below the ovarian fossa, to the attached border of the broad ligament beneath which it passes in its course to the uterus. On gaining a point about 2 cm. from the cervix and on a level with the internal os (Merkel), the uterine artery bends medially and crosses the ureter obliquely and in front. It then traverses dense connective tissue, and on approaching the lateral wall of the cervix bends sharply upward to course between the layers of the broad ligament along the lateral borders of the uterus, as far as the lateral angle. Immediately below the ovarian ligament the

FIG. 1702.



Transverse section of uterus through body. × 2.

uterine artery divides into its terminal branches distributed to the fundus, Fallopian tube, and ovary. In addition to a small branch to the ureter, just before bending upward it gives off the vaginal artery that passes downward and assists in supplying the cervix and the vagina. As it ascends along the sides of the uterus, from 5–10 mm. removed and surrounded by a dense plexus of veins, the very tortuous uterine artery sends numerous but variable branches to the cervix and body, as well as to the broad ligament, those distributed to the posterior surface being somewhat larger than those to the anterior (Robinson). The terminal branch passing to the fundus (ramus fundi) is especially strong and freely anastomoses with the corresponding vessel from the opposite artery, thus insuring exceptional vascularity to that part of the uterus in which the placenta is usually attached (Charpy). Twigs also accompany the ovarian and round ligaments. After the establishment of the junction between the ovarian artery and its ovarian branch, the uterine artery plays an important part in maintaining the nutrition of the ovary. On gaining the muscular coat the larger branches divide into vessels that penetrate the outer layer of the myometrium and within the inner muscular layer break up into numerous minute twigs that confer upon this stratum its highly vascular character. Within

the mucosa the capillaries surround the glands and form a superficial net-work beneath the epithelium.

The *veins*, already of considerable size within the inner muscular layer, emerge from the myometrium and form a dense plexus of thin-walled vessels that surround the uterine artery at the sides of the uterus between the layers of the broad ligament. The veins are arranged as an upper, middle, and lower group. The first of these includes the veins from the fundus and upper part of the body, which become tributary to trunks that join the ovarian veins and leave the pelvis by way of the suspensory ligament. The middle group comprises the venous radicles from the lower half of the body and upper part of the cervix that unite into one or two main stems that accompany the uterine artery. The lower group is formed by the veins from the most dependent part of the uterus, the anterior vaginal wall, and the posterior surface of the bladder. These unite into robust ascending stems that become tributary to the trunks following the uterine artery. The middle and lower groups freely anastomose with the vesical plexus and also communicate with the hemorrhoidal plexus.

The *lymphatics*, within the mucosa not demonstrable as definite vessels but only as uncertain clefts, constitute an intermuscular net-work of which the larger trunks follow the blood-vessels and establish communication between the cervical lymphatics and those of the body. On emerging from the myometrium a superficial (subserous) plexus is formed, especially over the posterior surface in the vicinity of the lateral angles; large trunks also accompany the blood-vessels along the sides of the uterus. The lymphatics from the cervix, usually two or three stems, pass to the lymph-nodes occupying the angle between the external and internal iliac arteries. According to Bruhns,[1] those from the remaining parts of the uterus follow different paths: one set, from the body, goes likewise to the iliac nodes; another, from the fundus, courses towards the ovary, and in company with the trunks from the latter organ follows the ovarian artery to terminate in the lumbar nodes. A third set, also from the fundus, eventually gains the lumbar glands after joining the lymphatics of the Fallopian tube, while a fourth group diverges from the fundus along the round ligament to become afferents of the inguinal lymph-nodes. In addition to free anastomosis among themselves, the uterine lymphatics communicate with those of the vagina, rectum, ovaries, Fallopian tubes, and broad ligament.

The **nerves** of the uterus, being chiefly destined for the involuntary muscle, are numerous and of large size to correspond with the highly developed myometrium. They are derived not only from the sympathetic system from the utero-vaginal subdivision of the pelvic plexus (the continuation from the hypogastric), but also directly from the second, third, and fourth sacral spinal nerves. According to the classic description of Frankenhäuser, the utero-vaginal plexus divides into two parts, the smaller of which is distributed to the posterior and lateral parts of the uterus, while the larger includes a chain of minute ganglia along the cervix and vaginal vault. One of these, the *cervical ganglion*, is especially large, and lies behind the upper part of the vagina, receiving, in addition to the sympathetic, spinal fibres from the sacral nerves and giving off twigs to the uterus. These latter pass to the uterine walls between the layers of the broad ligament, particularly at the sides in company with the blood-vessels, and penetrate the myometrium, to the fibre-cells of which the nerve-filaments are chiefly distributed; others pass into the mucosa to end beneath the epithelium.

Development and Changes.—In consequence of the medial rotation of the ventral border of the Wolffian body, the relations of the Müllerian to the Wolffian duct change. Instead of lying laterally to the Wolffian duct, as it does above, the Müllerian duct gains the inner side of that tube as they pass into the urogenital fold (page 2038) which prolongs the lower end of the Wolffian body into a median strand known as the genital cord. Within the latter, formed by the fusion of the plicæ urogenitales, the two Müllerian ducts lie next the mid-line, side by side and in contact with the Wolffian duct on either hand. Beginning about the eighth week, the opposed surfaces become united, the intervening septum disappears and the two Müllerian ducts are converted into a single tube from which the uterus is derived.

[1] Archiv f. Anat. u. Phys., 1898.

For a time this tube ends blindly and is continued to the urogenital sinus, with which it unites, as a solid cylinder of larger cells; this lumenless segment of the fused Müllerian ducts represents the anlage of the vagina. The extent to which the Müllerian ducts undergo fusion is early indicated by a sharp inward bend of these tubes just below the lower and medial ends of the Wolffian bodies, the flexure on each side corresponding to the attachment of fibres that pass to the anterior abdominal wall and later from the round ligament. The portions of the Müllerian ducts above this point remain separate and ununited and become the oviducts, those below undergo fusion and produce the uterus and vagina.

After the vaginal portion of the united Müllerian ducts acquires a lumen (by the end of the fourth month), the uterine and vaginal segments of the tube are differentiated by the tall cylindrical and the larger cuboidal epithelial cells that line the two portions respectively. The transition zone, which becomes progressively more marked, corresponds to the position where later the cylindrical uterine epithelium changes into the squamous vaginal cells at the inner margin of the external os. Soon the distinction between the uterine and vaginal portions of the genital canal is additionally emphasized by the forward curve of the former and the straighter downward course of the latter. The more definite division of the uterus from the vagina is effected by the appearance of crescentic thickenings of the anterior and posterior walls of the canal which mark the beginnings of the corresponding lips of the cervix. Distinction between the body and cervix is early suggested by the uterine epithelium, the cells lining the lower portion being taller, more cylindrical and numerous than those of the body. The connective and muscular tissue of the uterine wall are differentiated from the condensed mesoderm that surrounds the epithelial tube. Distinct muscle is not distinguishable before the fifth month, about which time the cervical glands also make their appearance (Nagel), thus anticipating by some weeks the development of the glands in the corpus uteri.

At birth the uterus measures about 3 cm. in length, of which the cervix contributes more than half, and is thicker and denser than the thin-walled and flaccid body. The characteristic arched form of the fundus is lacking and the lateral angles are prolonged into the tubes, often recalling a bicornate condition. The portio vaginalis is inconspicuous and projects to only a slight degree, although the plicæ palmatæ are well developed and not limited, as they later are, to the cervical canal, but extend throughout the uterine cavity. Since at this time the internal os is still immature, the division of the uterine cavity into an upper and a lower segment is only suggested. The general position of the uterus is higher than later, it, together with the bladder, lying above the level of the pelvic brim, with the fundus opposite about the fifth lumbar vertebra (Merkel). With the increasing capacity of the pelvis, the uterus sinks, so that by the end of the sixth year the external os is little higher than in the adult (Symington). Apart from the gradual development of the glands and the disappearance of the folds of the mucosa within the body, during childhood the uterus grows slowly until near puberty, when the body thickens, lengthens, and acquires the arched contours of its mature form. In its relatively long cervix and slightly prominent fundus, the uterus of the virgin retains the characteristics of early childhood. The repeated changes incident to the menstrual cycle, produce gradual thickening of the uterine walls and enlargement of the lumen, so that, even independently of pregnancy, the uterus increases somewhat in size and weight during the years of sexual activity.

After the cessation of menstruation, between the forty-fifth and fiftieth years, the uterus suffers gradual atrophy (involution). This first affects the cervix, which becomes smaller and more slender, the entire organ in consequence assuming a more pronounced pyriform outline. The general reduction in the size and prominence of the vaginal portion is accompanied by atrophy of the plicæ palmatæ of the cervical canal. The walls of the body are also involved and become thinner and less resistant with atrophy of the muscular tissue and decreased vascularity, and hence paler color, of the mucosa. For a time the uterine cavity is enlarged, but, later, sharing in the general atrophy and not inconsiderable diminution in size of the organ, the lumen likewise undergoes reduction and, in some cases, suffers obliteration in the vicinity of the internal os.

Changes during Menstruation and Pregnancy.—Although liberation of a mature ovum may occur at any time, such independence is exceptional, and in the vast majority of cases ovulation and menstruation are synchronous processes, the uterine changes occurring regularly, every twenty-eight days, only when the ovaries are functionally active. In anticipation of the possible reception of a fertilized ovum, the uterine mucous membrane becomes swollen, excessively vascular and hypertrophied, with conspicuous enlargement of the subepithelial blood-vessels and the glands. The resulting thickened and modified mucosa, now from 3–6 mm. in thickness, offers a soft velvety surface favorable for the implantation of the embryo-sac. Should this purpose be realized, the hypertrophy proceeds, and the lining of the uterus is converted into the deciduæ and takes an important part in the formation of the placenta and attached membranes (page 44). If, on the contrary, fertilization does not occur, the proliferative processes are arrested and the hypertrophied mucosa (now called the *decidua menstrualis*) enters upon regression. Incidental to the latter are subepithelial extravasation and rupture and partial destruction of the epithelium, followed by the characteristic discharge of blood. While usually the destruction of the mucosa is limited to the epithelium, it is probable that at times the superficial layer of the subjacent tissue is involved.

During pregnancy the most conspicuous changes are occasioned by the growth necessary to accommodate the rapidly augmenting volume of the uterine contents, by the provision of an adequate source of nutrition and protection for the fœtus, and by the development of an efficient contractile apparatus for the expulsion of the same. From an organ ordinarily weighing about 45 grams (1½ oz.), measuring 7 cm. in length and possessing a capacity of from 3–5 cc., by the close of pregnancy the uterus has expanded into a rounded or oval sac about 36 cm. (14 in.) in its greatest length, from 900–1000 grm. (about 2 lbs.) in weight and with a capacity of 5000 cc. (169 fl. oz.) or more. This enormous increase depends especially upon the hypertrophy of the muscular coat of the organ, which during the first half of pregnancy becomes greatly thickened, but later thinner and membranous owing to stretching. The increase in this coat results from both the growth of the previously existing muscle-cells and, during the first half of pregnancy, the development of new muscle elements. The individual cells may increase tenfold in length and measure between .4–.5 mm. Although the cervix actually almost doubles in size, its growth is overshadowed by that of the body, since it remains relatively passive. During the first five months, the mucous membrane of the body of the uterus also becomes greatly hypertrophied, in places attaining a thickness from 7–10 mm. The glands and blood-vessels, particularly the arteries, enlarge and, within the specialized area, are concerned in the formation of the placenta (page 48). The cervical mucosa takes no direct part in the formation of the deciduæ, although it thickens and is the seat of enlarged glands that secrete the plug of mucus that for a time occludes the mouth of the uterus.

After the termination of pregnancy, the uterus enters upon a period of involution and repair, the excessive muscular tissue undergoing degeneration and absorption and the lacerated mucosa regeneration, the latter process being completed in from five to six weeks (Minot). In sympathy with the growth of the myometrium, the round ligaments enlarge and also show marked augmentation of their muscular tissue. The peritoneal relations are disturbed by the excessive bulk of the uterus, so that at the sides the layers of the broad ligament become separated.

Variations.—The chief anomalous conditions of the uterus depend upon defective development or imperfect fusion of the Müllerian ducts by the union of which the normal organ is formed. Arrested development of the lower part of these fœtal canals accounts for entire absence of the uterus and vagina. Depending upon the extent to which failure of fusion occurs, all degrees of doubling are produced. In the most pronounced cases, in which the Müllerian ducts remain separate throughout their entire length, two completely distinct uteri and vaginæ may result, each pair being capable of performing the functions of the normal organs. On the other hand, slight indentation of the fundus may be the only evidence of imperfect union. Between these extremes all gradations occur; the body may be completely cleft (*uterus bicornis*), with or without divided cervix; or the duplicity may be partial and limited to branching of the fundus; or the faulty fusion may be manifested by only a partition, more or less complete, that divides the uterine cavity into two compartments (*uterus septus*), although the external form of the organ is almost or quite normal. When, in conjunction with any of the foregoing variations, one of the component Müllerian ducts fails to keep pace in its growth, all degrees of asymmetrical development may result, from complete suppression of one of the tubes in a bicornate uterus to merely unilateral diminution of the fundus. Subsequent arrest of what to a certain stage was a normal development may result in permanent retention of the fœtal or infantile type of uterus.

PRACTICAL CONSIDERATIONS: UTERUS AND ITS ATTACHMENTS.

In the female the pelvis is subdivided into two compartments by a fold of peritoneum reflected from the floor and sides of the cavity. This fold passes from one side to the other and includes between its layers in the median line the uterus. On each side of the uterus it is known as the broad ligament, and encloses the uterine

appendages, their blood-vessels, together with their nerves and their enveloping connective tissue. This transverse fold of peritoneum is analogous to the mesentery of the small intestine, serving the same purpose for the uterus and its appendages—*i.e.*, to hold them in position and to transmit their blood-vessels and nerves.

The *posterior compartment* of the pelvis, the *recto-uterine*, is the larger and deeper of the two. The lower portion of it, included between the two recto-uterine folds of the peritoneum, is the pouch of Douglas, or recto-vaginal pouch, because it lies between the rectum and the upper fourth of the vagina, from which it is separated only by subperitoneal connective tissue. The rectum, bulging forward the posterior wall, and the ovaries, hanging from the anterior wall, tend to fill this compartment, the remaining space being occupied by small intestine and a portion of the sigmoid flexure.

Abnormally it may be encroached upon by a retroposed uterus, which tends to drag downward and backward its appendages, the tubes and ovaries, towards Douglas's pouch, where they may be palpated by the finger through the vagina. Because of the greater depth of the posterior compartment and because of the fact that abscess and other pelvic operative conditions are usually situated in it, it must almost always be drained, if drainage is necessary after operation in this region.

The *anterior* or *vesico-uterine compartment* of the pelvis extends below only to the isthmus of the uterus. The remaining supravaginal portion of the cervix is in close relation to the bladder, but the loose intervening layer of subperitoneal tissue permits a ready separation of the two in the operation for the removal of the uterus (hysterectomy). Since the body of the uterus inclines forward, normally, touching the bladder, the space in this compartment is slight. It exceptionally contains a few coils of small intestine, and may lodge also a part of the sigmoid flexure.

A *tumor* or *pregnant uterus* filling the pelvis may press upon the iliac veins, producing œdema and varicose veins of the lower extremities, of the vulva, and of the rectum (hemorrhoids); upon the lumbar and sacral nerves, causing cramps, neuralgia, or paralysis; upon the bladder, with resulting vesical irritability and pain; upon the rectum, inducing constipation and hemorrhoids; upon the ureters, giving rise to hydronephrosis; or upon the renal veins and kidney, producing albuminuria and possibly uræmia.

The **uterus** is held in position between the bladder and the rectum by its ligaments, and is kept from dropping to a lower level (prolapse) mainly by the support received from atmospheric pressure acting through the floor of the pelvis. The broad or lateral ligaments attach it and its appendages—the Fallopian tubes and ovaries—to the sides of the pelvis. The round ligaments act chiefly in tending to prevent retro-displacements. The musculo-fibrous utero-sacral ligaments and the anterior and posterior reflections of peritoneum materially steady the cervix, which is also fixed by its attachments to the bladder and vagina. Moreover, the intra-abdominal pressure applied through the intestinal convolutions that are normally in contact with its posterior surface aids in holding it in position. The body of the uterus is more freely movable than the cervix, and in spite of its supports the uterus, as a whole, is one of the most mobile of the viscera. The cervix, for example, may easily be made, through traction by means of a tenaculum, to present at the orifice of the vagina, in such operations as amputation of the cervix, repair of lacerations, or dilatation and curettement. On account of its mobility, its intrapelvic situation, and the elastic support received from the bladder, and indirectly from the levator ani muscles, the uterus is very rarely injured by blows on the abdomen. If upon examination it is found to be fixed, or not easily movable, some abnormal cause should be sought for, such as pelvic inflammations or tumors.

The essential conditions in the production of a *prolapsed uterus* obtain when the uterus is the seat of subinvolution from any cause, especially a puerperal infection, and the pelvic floor is relaxed or torn. The stretching of the pelvic ligaments has then not been fully overcome by later contraction, and the atmospheric support (dependent upon a tightly closed vaginal outlet) is lacking because of the weakened perineal floor. As the uterus reaches a lower level its ligaments become truly "suspensory" and resist its further downward progress as soon as their uterine attach-

ments are below their pelvic attachments. Normally their insertions and origins lie approximately in the same horizontal plane when the woman is erect (Penrose).

The integrity of the levator ani muscle, ensuring a well-closed vaginal outlet, is the most important factor in supporting the uterus within the pelvis. It keeps the outlet forward under the pubic arch out of the line of abdominal pressure, gives it the form of a narrow slit, preventing the protrusion of the pelvic viscera, and directs the axis of the vaginal canal forward instead of directly downward, so that the intra-abdominal pressure strikes the pelvic floor at a right angle ; and by aiding in maintaining the vagina in its normal condition of a closed slit with its walls in contact, it prevents disturbance of the forces which hold the uterus in place. If a laceration of the perineum converts the vagina into an open air-containing tube, the equilibrium of these forces is destroyed and prolapse often follows. In severe cases of prolapse the ureters are so stretched that, at their vesical ends, their lumen is narrowed and ureteral dilatation or hydronephrosis may result.

Anterior and *posterior flexions* of the uterus occur at the isthmus, which is the weakest point and is the junction of the larger and more movable portion—the body —with the smaller and more fixed portion—the cervix.

On account of the normal *anteflexion* of the uterus, it is not always easy to decide in a given case whether the degree of anteflexion is normal or abnormal. When it is abnormal the most important symptom is dysmenorrhœa, from obstruction of the canal by the flexion ; if irritability of the bladder occurs, it is probably reflex in its origin.

Anything which weakens the support of the uterus, or increases its weight, tends not only to cause prolapse, but also to the production of *retroflexion* or *retroversion* of the *uterus*, the first degree of prolapse being associated with some retrodisplacement. The uterus then loses its normal anteversion, and the intra-abdominal pressure is brought to bear on its anterior surface, especially if the patient is either confined too long in the supine position after labor, with the abdomen too tightly bandaged, or if she leaves her bed too soon or undertakes any physical work.

The uterus is larger and heavier than normal, as a result of imperfect involution ; the uterine ligaments are lax ; the vagina and the vaginal orifice are relaxed, and the support of the pelvic floor is consequently deficient ; the abdominal walls are flabby and the retentive power of the abdomen is diminished. These are also the causes that favor prolapse of the uterus ; in fact, a slight degree of uterine prolapse usually accompanies such cases of retrodisplacement. A certain amount of retroversion must always exist before the uterus can pass along the vagina. It must turn backward, so that its axis becomes parallel to the axis of the vagina (Penrose).

In the purely *retroverted* positions the uterus revolves on the isthmus as on a pivot, so that as the fundus goes in one direction the cervix passes in the other. Therefore, as the cervix is turned forward against the base of the bladder, the fundus presses backward on the rectum, often producing reflex symptoms.

The uterus may be found inclined to one side—more usually the fundus to the left, and the cervix, on account of the presence of the sigmoid and rectum on the left side, to the right. Unless extreme, such inclination is not to be regarded as pathological.

Between the layers of the **broad ligaments** is a quantity of loose adipose cellular tissue, the parametrium, separating the contained structures—those of the most importance being the tubes and ovaries with their vessels and nerves—from one another and from the serous membrane. This cellular connective tissue is continuous with the surrounding subperitoneal areolar tissue of the pelvis, and is especially abundant near the base of the broad ligaments.

In *pelvic cellulitis* there is infection of this loose cellular tissue, usually through the lymphatics and often puerperal in origin. It may follow other septic intrapelvic conditions, especially salpingitis, but a simple cellulitis unaccompanied by tubal inflammation is in the vast majority of cases due to infection through the uterus from a septic endometritis. Because of the laxity of the tissue it may spread rapidly and extensively in virulent cases. It may extend backward along the utero-sacral ligaments, then upward along the retroperitoneal tissue, as far as the kidneys. It may pass forward and upward to the groin, where, should an abscess form, it may be

opened. It may also burrow into the vagina or rectum. Suppuration takes place, however, in only a small percentage of cases.

The condition is usually recognized by the rapid swelling and induration at the sides of or behind the uterus, and in closer relation to it than is the swelling of a pyosalpinx or of an ovarian abscess. Pelvic collections of pus of this nature may be evacuated through the vagina by an incision made close to the cervix,—to avoid the ureters and the uterine arteries; but it should be remembered that this procedure does not remove the focus of primary infection, such as a diseased Fallopian tube.

Blood collections (hæmatoceles) or *tumors* (intraligamentous) may also occur between the layers of the broad ligaments.

The narrow lower border of each ligament lies on the floor of the pelvis, but is separated from it by a thick layer of subperitoneal tissue, in which the uterine artery with its veins passes nearly transversely inward from the internal iliac artery at the side of the pelvis to the cervix at about the level of the vault of the vagina.

The ureter, on its way from behind forward to the bladder, passes through this loose cellular tissue just below the base of the broad ligament. It lies close under the uterine artery from one-half to one inch from the side of the cervix. It is within this short distance that the uterine vessels are tied, either from within the abdomen or from the vagina, according to the method of operation, in the removal of the uterus (hysterectomy). The inclusion of the ureter within the ligature is one of the greatest dangers in this operation. This accident is more likely to occur if the artery is crowded closer to the ureter of one side, by a tumor or other mass, in the opposite side of the pelvis. The ureter is also in danger, as it lies along the side and floor of the posterior compartment of the pelvis. It may there be injured in the removal of adherent masses, such as inflamed tubes and ovaries, or of retroperitoneal tumors or cysts. Calculi in the vesical ends of the ureters may be removed through the vaginal wall (page 2020).

The free upper border of the broad ligament between the fimbriated extremity of the tube and ovary and the side of the pelvis—the suspensory ligament of the ovary or the infundibulo-pelvic ligament—is of practical importance because, in addition to supporting the ovary, it contains the ovarian vessels where they are usually tied in the operations for the removal of the uterus or its appendages. Kelly calls attention to a space immediately below the vessels in this region, where the two layers of the peritoneum, forming the broad ligament, come close together. By passing a ligature through this membranous interval and tying over the top of the broad ligament, all the ovarian veins and the artery are included. If the uterine vessels also are tied by a separate ligature, at the cornu of the uterus, there should be no danger of hemorrhage in a salpingo-oophorectomy; or, if the uterine vessels are secured at the sides of the cervix, in the floor of the pelvis, and the ovarian vessels are ligated, as above, on both sides of the pelvis, the hemorrhage will be controlled for a hysterectomy.

The **round ligaments,** passing outward and forward from the sides of the uterus through the internal ring and inguinal canals to the labia majora, tend by their direction to maintain the uterus in its normal anteflexed position. When retrodisplacements of the uterus do occur these ligaments become stretched and lengthened. They have frequently been shortened by operation to correct such displacements. This may be done by the extra-abdominal method in the inguinal canal (Alexander's operation), or within the abdomen (Palmer Dudley operation), the latter method permitting a more accurate estimate of the special peculiarities or difficulties of a given case.

Occasionally in the adult—always in the fœtus and in 20 per cent. of cases in children (Zuckerkandl, quoted by Woolsey)—a patulous process of peritoneum, the canal of Nuck, accompanies the round ligament, lying above and in front of it for a variable distance through the inguinal canal. It is analogous to the vaginal process of peritoneum which descends with the testicle, and, like it, predisposes to congenital inguinal hernia (page 1767) and to hydrocele (page 1953). Should its lumen become constricted at some point, the portion beyond the obstruction may secrete fluid and give rise to the so-called "cyst of the canal of Nuck," which is analogous to an encysted hydrocele of the cord in the male (page 1953).

THE VAGINA.

The vagina is a flattened muscular tube, lined with mucous membrane and about 7.5 cm. (3 in.) long, that extends from the genital cleft enclosed by the labia minora below to the uterus above, to the lower segment of which it is attached a short distance above the external os. From this relation and the direction, downward and backward, of the portio vaginalis, the vagina is seemingly pierced obliquely by the uterus, whose external os looks towards the posterior vaginal wall. In the erect posture the long axis of the vagina is approximately straight, directed from below upward and backward, and corresponds in general with the lower part of the pelvic axis. With the horizontal plane it forms an angle of about 70°, and with the axis of the cervix one that is usually somewhat more than a right angle.

The arched upper blind end of the vagina, known as the *vault* (**fornix vaginae**), is largely occupied by the obliquely placed portio vaginalis and thereby reduced to an annular groove that surrounds the neck of the uterus. This groove is deepest behind, where it constitutes the *posterior fornix*, a narrow pouch from 1.5–2 cm. in length lying between the cervix and the adjacent vaginal wall. The recess in front of the cervix, the *anterior fornix*, is shallow and only slightly marked. In consequence, the length of the posterior wall of the vagina, measured from the summit of the posterior fornix to the vaginal orifice, is from 8.5–9 cm. (3⅜–3⅝ in.), that of the anterior wall being about 7 cm. (2¾ in.), or from 1.5–2 cm. shorter.

FIG. 1703.

Vagina of virgin, posterior wall has been removed exposing rugous condition of anterior wall.

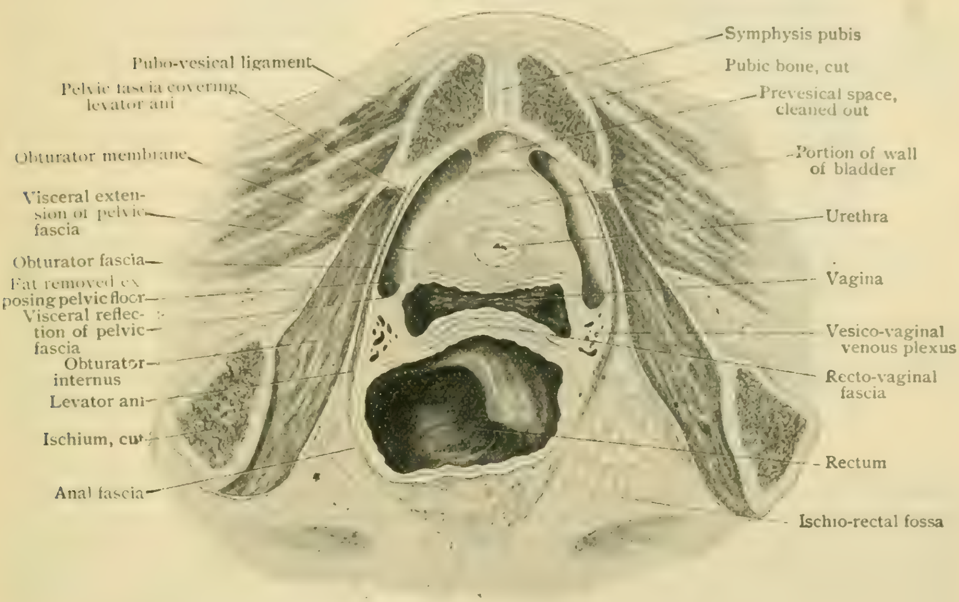
The opening at the lower end of the vagina (**orificium vaginae**) is contracted, and in the virgin is still further narrowed by a duplicature of mucous membrane, the *hymen*, of variable form but usually crescentic in outline, that stretches from the posterior wall forward and occludes more or less the vaginal entrance. After rupture the hymen is for a time represented by a series of irregular or fimbriated projections that become the *carunculæ hymenales*. These surround the opening of the vagina and undergo reduction and partial effacement after childbirth. The anterior and posterior walls of the main and widest part of the canal (**corpus vaginae**) are modelled by median elevations (**columnae rugarum**), from which numerous oblique folds diverge laterally. These markings, most pronounced in the lower half of the vagina, are particularly conspicuous on the front wall. Here the anterior column is beset with close V-like ridges and ends below in a crest-like elevation—the *carina urethralis*—that lies behind the urethral orifice.

Relations.—With the exception of the triangular area, from 1.5–2 cm. long, over the uppermost part of the posterior wall, where the bottom of the recto-uterine pouch reaches the canal, the vagina is devoid of peritoneum, being attached to the surrounding organs by areolar tissue. In front its upper fourth is in relation with a small part of the fundus and the trigone of the bladder, being attached to the vesical wall by loose connective tissue. Embedded within the latter and surrounded by veins, course the converging ureters, which reach the anterior vaginal wall at about the level of the lower end of the cervix. Below the bladder, the anterior wall of the vagina and the urethra are intimately connected by the intervening dense fibrous tissue (**septum urethrovaginalis**), with which the vaginal wall blends without sharp demarcation. In consequence of the forward curve of the urethra this partition broadens below.

Behind, the chief relation is with the rectum, which is separated from the uppermost part of the vagina, for a short distance (from 1.5–2 cm.), by the pouch of

Douglas. Below the latter, as far as the levator ani muscles, the vagina and bowel are connected by the dense recto-vaginal septum, strengthened by the intervening prolongation of the pelvic fascia. Further down, where the rectum bends backward, the partition broadens into a wedge-shaped mass, the *perineal body*, which on sagittal section appears as a triangle with the base below in the perineum (Fig. 1700). At the sides the vagina is embraced by, although unattached to, the median (pubo-rectal) portion of the levator ani muscles, which, in conjunction with the pelvic fascia, afford efficient support. Below the pelvic floor, the vagina gains additional fixation in passing through the triangular ligament with which it is intimately attached. In relation with the lower end of the vagina lie the bulbus vestibuli and Bartholin's glands. The triangular interval, on each side, between the levator ani and the pelvic fascia and the lateral surface of the vagina, is occupied by the veins of the vesico-

Fig. 1704.



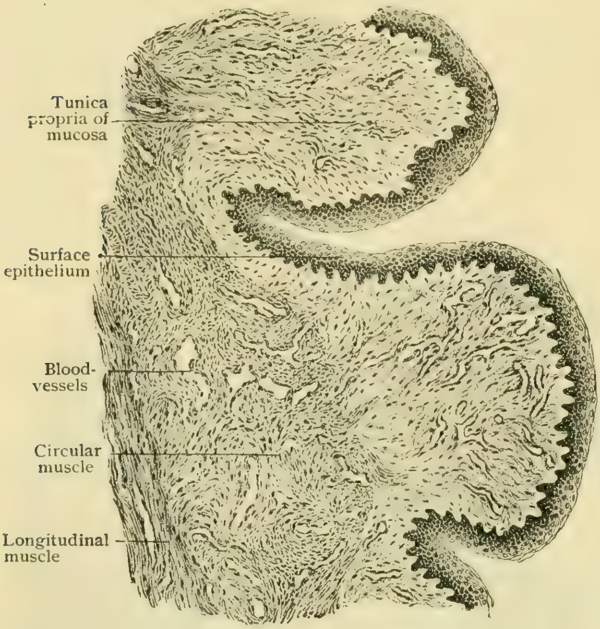
Anterior portion of horizontal section through pelvis, of female, passing just below bladder; visceral reflections of pelvic fascia are seen extending to bladder, vagina, and rectum.

vaginal plexus that above surrounds the ureter and the vaginal branches of the uterine artery.

Structure.—The vaginal walls, from 2–3 mm. thick, include a mucous and a muscular coat, supplemented externally by an indefinite fibrous tunic. The mucous coat consists of a tunica propria, exceptionally rich in elastic fibres and veins, the inner surface of which is beset with numerous conical papillæ that encroach upon the overlying epithelium, but do not model the free surface. The epithelium, from 0.15–0.20 mm. thick, is stratified squamous in type and possesses a superficial stratum of plate-like cells (.020–.030 mm. in diameter) that resemble the epidermal elements of the skin and are constantly undergoing maceration and abrasion. Although normally moistened by a thin mucous secretion of acid reaction, the vagina is devoid of true glands and probably derives its lubricating fluid for the most part from the uterine glands, the alkaline secretion becoming modified. Small nodules of lymphoid tissue are scattered within the mucosa, especially in the upper part of the canal. The duplicature of the mucous membrane forming the hymen corresponds in structure with that lining other parts of the canal. The muscular coat, which directly supports the mucosa without the intervention of a submucous tunic, consists of bundles of involuntary muscle that are arranged, although not with precision, as an inner circular and an outer longitudinal layer. The latter is best developed over the

anterior vaginal wall, from which bundles of muscular tissue are continued into the urethro-vaginal septum; behind, bundles pass into the recto-vaginal partition. Above, the vaginal muscle is directly continuous with that of the uterus and below penetrates the perineal body. Within, the conspicuous columnæ rugarum, the muscular coat, as well as the mucous, is thickened, the elevations acquiring the character of erectile tissue owing to the great number of veins intermingled with the irregularly disposed muscle bundles. After piercing the superior layer of the triangular ligament and in the vicinity of the orifice, the vaginal walls receive strands of striated fibres derived from the middle part of the compressor urethræ (m. urethro-vaginalis) and the bulbo-cavernosus muscles.

Fig. 1705.



Section of wall of vagina. × 80.

Vessels.—The *arteries* supplying the vagina, all derived from the internal iliac, reach the organ by various routes. The upper part of the vagina is supplied by twigs continued from the cervical branch of the uterine arteries, that descend along the sides of the canal and communicate with the branches from the middle hemorrhoidal and vaginal (vesico-vaginal), that are distributed to the middle and lower portions of the vagina respectively. Those from the vaginal, of the two sides, form encircling anastomoses from which an unpaired vessel (*a. azygos vaginæ*) frequently is given off on the posterior, and sometimes anterior, wall. Additional branches pass to the lower part of the vagina from the arteries to the bulbus vestibuli from the internal pudics. Free anastomosis exists between the vessels derived from these various sources. The *veins*, numerous and large, after emerging from the muscular tunic unite on each side to form the rich vaginal plexus that extends along the sides of the genital canal and communicates with the vesical and uterine plexuses. It receives tributaries from the external generative organs and is drained by a trunk, the vaginal vein, that passes from its upper part to the internal iliac vein.

The *lymphatics* within the mucous membrane form a close net-work that communicates with the lymph-vessels of the muscular coat. The collecting trunks pass from the upper and middle thirds of the vagina, in company with those from the cervix uteri, chiefly to the lymph-nodes along the internal iliac artery. Additional stems from the posterior vaginal wall encircle the bowel and terminate either in the rectal or the lumbar nodes (Bruhns). The lymphatics from the vicinity of the vaginal orifice pass chiefly to the upper median group of inguinal nodes; some, however, join the lymph-paths from the upper segments.

The **nerves** are derived from the hypogastric sympathetic plexus, through the pelvic, and from the second, third, and fourth sacral nerves. The immediate source of the sympathetic fibres is the cervical ganglion, at the side of the neck of the uterus, from which, in association with the sacral branches, twigs pass to form, on each side, the vaginal plexus that embraces the vagina and provides filaments chiefly for the involuntary muscle of its walls and blood-vessels. The sensory fibres supplying the mucous membrane of the upper part of the vagina are meagre, since, under normal conditions, this part of the canal possesses sensibility in only very moderate degree. Towards the orifice, the vagina receives fibres from the pudic nerves which endow

the mucous membrane of the lower third with greater sensibility and send motor filaments to the striated muscle surrounding the entrance. Sensory nerve-endings of different kinds have been described within the mucosa.

Development.—The vagina is formed by the downward extension and fusion of the Müllerian ducts. After union of the latter with the posterior wall of the urogenital sinus and the appearance of a lumen, which at first is wanting, the genital canal opens into the sinus by an aperture, later the orificium vaginæ, that lies between and closely united with the Wolffian ducts. The latter subsequently atrophy and disappear, but may, in exceptional cases, persist to a greater or less extent as Gartner's ducts. The entrance of the immature vagina is early guarded by an annular fold that becomes the hymen and owes its differentiation to a pouching of the vaginal wall behind a zone of thickened epithelium (Nagel). For a time, usually until about the seventh month of fœtal life, the orifice of the vagina is occluded by epithelium. The proliferation and thickening of the vaginal lining, which begin below, gradually extend upward and result in the production of conspicuous rugæ, which, during the last months of pregnancy, cover not only the entire surface of the vagina, but also that of the cervix, which even at birth is slightly corrugated. In consequence of the increasing irregularity and thickening of the mucosa, the vaginal walls, which for a time are adherent, become separated and the lumen of the canal is definitely established, remains of the desquamated epithelium being often visible in the new-born child. Distinct muscular tissue within the vaginal wall is not distinguishable before the fifth month.

At birth, the vagina is relatively long (Fig. 1623) and its wall is comparatively thick, with conspicuous rugæ extending as far as the vault. During the early years of childhood the vagina remains small and vertical, but after the tenth year grows rapidly, the increased width causing reduction in the rugæ, which from now on are feebly marked in the upper part of the canal. After undergoing the stretching incident to labor, the rugæ and columns are much less conspicuous, and after repeated distention may suffer almost complete effacement. The vagina shares in the general involution of the sexual organs, and in advanced years loses much of its former elasticity and undergoes atrophy.

Variations.—The most important variations depend upon defective development and imperfect fusion of the component Müllerian ducts, and are, therefore, often associated with anomalies of the uterus. When these tubes fail to reach the urogenital sinus, the vagina ends blindly above the vestibule; or when their lower segments are stunted, the vagina (and often uterus) may be entirely wanting. Duplication, more or less complete, follows persistence of separate or imperfectly fused Müllerian ducts. The doubling may not extend throughout the length of the vagina, but may be represented by an imperfect and partial septum, isolated bands, or a twin hymen. Unequal development of the Müllerian ducts accounts for the marked asymmetry occasionally observed, notably in double vaginæ, where one canal may be very rudimentary or end blindly. The hymen presents great variety in the details of its opening, which may be crescentic, circular, stellate, linear, double, or multiple (*hymen cribriformis*). It may be a mere pin-hole or entirely wanting (imperforate), in which case retention of menstrual discharges occurs.

PRACTICAL CONSIDERATIONS: THE VAGINA.

Congenital malformations of the vagina, such as absence of the vagina, rudimentary vagina, or vaginal septa, are usually associated with corresponding errors in development of the uterus. While other malformations due to faulty union of the Müllerian ducts occur, the more common is a uterus bicornis, or a double uterus and vagina. They are not incompatible with pregnancy, labor and the puerperium often passing without unusual incident; indeed, this condition is usually recognized by accident, since no external evidence is seen. Conception may occur on one or both sides simultaneously. A vaginal septum which interfered with the progress of the head should be divided. From imperfect development of one side of a bicornate uterus, pregnancy may lead to great danger of rupture of the weak uterine wall, or to a failure to expel the child.

While varying within normal limits with the distention of the bladder, when the latter is empty the axis of the fundus of the uterus lies at about a right angle with the vagina. The inner or uterine end of the broad ligament is, except at its base,

more nearly horizontal than vertical in direction. As a result of this position of the uterus, it will be seen that the lower surface of the cervix presents against the posterior vaginal wall, and that, therefore, this wall of the vagina must be longer than the anterior. The posterior wall is usually about three and a half inches long; and the anterior about two and a half to three inches. The length of the ordinary finger is about three inches; it can, therefore, reach the anterior fornix of the vagina and anterior lip of the cervix. To explore the posterior fornix of the vagina considerable pressure is required. To palpate structures in Douglas's cul-de-sac the bimanual method of examination will be necessary, and a relaxed abdominal wall, to obtain which a general anæsthetic may exceptionally be required. An empty bladder facilitates a bimanual examination. In the knee-chest posture the vagina becomes distended with air, permitting a more thorough visual examination of its walls. The rectum posteriorly, and the base of the bladder and the urethra anteriorly, are within reach of the finger in the vagina. Calculi, either in the lower ends of the ureters (*vide supra*) or in the bladder, can be removed through the anterior vaginal wall (page 2015).

The intravaginal portion of the cervix uteri can, with little or no pain, be grasped by a tenaculum and drawn down towards the vaginal orifice so that local applications can be made. It is so insensitive that such applications, even when strong and irritating, do not necessitate the use of an anæsthetic. Since it is the part of the cervix most exposed to traumatism and infection, it is the most frequent seat of pathological lesions, such as the so-called "erosions." Persistent—*i.e.*, unhealed—lacerations are often sources of irritation, of reflex pains, and of some forms of dysmenorrhœa. Much of the pelvic pain, associated with them, is probably due to pelvic lymphangitis or lymphadenitis (Penrose). These lacerations seem to invite the development of cancer. Primary involvement of the body of the uterus is comparatively rare, the great majority of cancers of the uterus beginning in the cervix. As a result of the relations and contiguity of the cervix to surrounding important structures, such as the bladder, ureters, and rectum, the prognosis of cancer of the cervix is less favorable than that of the body of the uterus, where infiltration of neighboring structures does not occur so early. As a rule, dissemination by lymphatic channels from carcinoma of the cervix, affects first the sacral or the iliac glands; carcinoma of the body of the uterus is more likely to involve the lumbar glands surrounding the common iliacs, the aorta, and the vena cava. Pressure on the last-named vessel may result in œdematous swelling of the lower extremities or in ascites.

An hypertrophied cervix shows as an increased projection into the vagina and a deepening of the vaginal fornices. This condition may be a cause of sterility.

The vagina is most roomy in its upper portion, and is narrowest at its lower end, where it passes through the triangular ligament and is surrounded by the constrictor vaginæ muscle. This favors the retention of blood-clots within the vagina during the menstrual period and after labor. Spasmodic contraction of this muscle (vaginismus) is described as being sometimes strong enough to prevent coitus and to call for surgical treatment, though such cases, if they exist at all, are due to reflex irritation, such as from urethral caruncle. The dilatation of the vagina seems to be limited only by the pelvic wall. In nullipara the rugosity of its mucous membrane—necessitated by its great changes in diameter—is marked. The transverse folds favor retention of secretions and of discharges resulting from infection and render sterilization of the vagina difficult. Vaginitis may be followed by endometritis, as the uterine and vaginal mucosæ are directly continuous.

The hymen rarely may have no opening, when it will require incision to relieve the obstructed first menstrual flow. The exact importance to be attached to the presence or absence of the hymen in medical jurisprudence is still undetermined. While it is usually broken at the first coitus, it may remain intact until the first parturition. Therefore its presence does not prove virginity. Its original perforation may have been large enough to leave little or no evidence of the membrane, so that its absence does not prove that coitus has taken place.

Fistulæ between the bladder and vagina (vesico-vaginal), between the urethra and vagina (urethro-vaginal), between the rectum and vagina (recto-vaginal), and between the cervical canal and the bladder (utero-vesical), may occur.

Recto-vesical fistula in a woman has followed ischio-rectal abscess, after the discharge of which the patient passed gas and fæcal matter through the urethra (Noble).

Vesico-vaginal fistulæ are usually due to sloughing consequent upon the impaction of the head in a difficult labor; they are not due, as erroneously believed, to the use of forceps, but to too long delay in using them (Emmet).

Urethro-vaginal fistulæ following labor are rare. More frequently the communication between the vagina and the upper part of the urethra is part of a larger opening into the bladder. It is in reality a *vesico-urethro-vaginal* fistula.

Vesico-uterine fistulæ are usually due to a tear extending forward through the anterior vaginal fornix into the bladder, and upward along the cervical canal. The lower part of the tear heals, leaving an opening between the bladder and cervical canal, the urine dribbling outward from the bladder into the cervical canal and thence into the vagina. If the lower part of the tear does not heal, we then have a *vesico-utero-vaginal* fistula.

Recto-vaginal fistulæ are found usually at the upper or lower end of the vagina. At the upper end they are most frequently due to extension of an epithelioma of the cervix into the rectum, and in the lower end to incomplete closure of a torn perineum extending into the rectum. They are very rarely due to labor itself.

THE FEMALE EXTERNAL GENITAL ORGANS.

The external generative organs of the female include those parts of the reproductive apparatus that lie below the triangular ligament and in front of and below the pubic arch. They are the *labia majora*, with the *mons pubis* above and the *urogenital cleft* between them, the *labia minora* or *nymphæ*, and the enclosed *vestibule*, the *clitoris* and the *bulbus vestibuli*, together with the *glands of Bartholin;* within the vestibule are the orifices of the urethra and of the vagina. Of these structures, collectively termed the *pudendum* (**pudendum muliebre**), or *vulva*, in the upright posture usually little more than the mons pubis and the labia majora are visible, although exceptionally the labia minora and the clitoris may be seen within the genital fissure.

THE LABIA AND THE VESTIBULE.

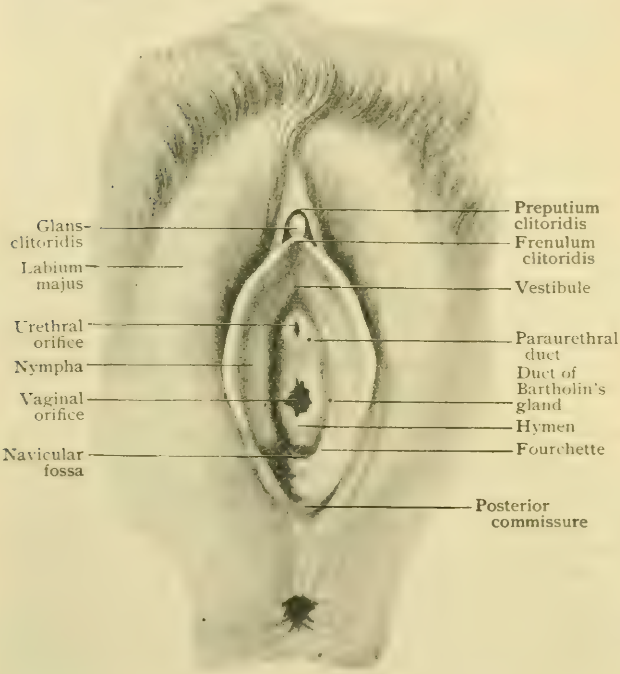
The labia majora (**labia majora pudendi**) are two prominent rounded cutaneous folds, the homologue of the scrotum, about 7.5 cm. (3 in.) long and 2.5 cm. thick, that extend backward from the mons pubis and enclose between their medial surfaces the *urogenital cleft* (**rima pudendi**). Above, their inner margins are continuous (**commissura labiorum anterior**) over the ridge formed by the body of the clitoris; behind, where their tapering ends blend with the perineum, they are connected by a transverse fold (**commissura labiorum posterior**), often only slightly marked and sometimes wanting, that crosses the mid-line in advance of the anus. Their outer surface is covered with thick, dark-hued integument and beset with hairs, in varying profusion, that encroach for a limited zone on the inner surface of the labia and may extend as far as the anus. The medial surface, on which the hairs are few and minute, is clothed with skin of much more delicate texture, that at the bottom of the nympho-labial furrow passes onto the outer surface of the nymphæ. In addition to the skin, each labium consists of a layer of subcutaneous fat, between which and the integument in the posterior half, a thin stratum of involuntary muscle (**tunica dartolabialis**) is continued forward from the dartos of the perineum and represents the similar but better developed sheet in the scrotum. The centre of the labium is occupied by a fairly well defined mass of fat (**corpus adiposum**) that is connected with the adipose tissue within the inguinal canal continuous with the subperitoneal tissue and is, therefore, of different derivation than that of the subcutaneous fat, from which it is separated by a delicate fascia. Into the latter are inserted some of the fibres of the round ligament of the uterus that ends within the labium majus. Sweat and sebaceous glands are numerous within the integument of the labia.

The **mons pubis** or **Veneris,** as the triangular rounded eminence above the genital cleft is called, consists of a cushion of fat, enclosed by dense skin and thickly covered with hair. The subcutaneous fatty layer, usually from 2–3 cm. thick, but

sometimes as much as 8 cm. or more, is supported by connective-tissue septa that pass from the underlying periosteum to the skin, whereby the tension of the latter is maintained.

The **labia minora,** or **nymphæ** (**labia minora pudendi**), are two thin folds of delicate skin that, for the most part, lie concealed between the larger labia, unless the latter are separated, and enclose the vestibule. Their length is from 2.5–3.5 cm., their width about half as much, and their thickness from 3–5 mm. Near its anterior end, each labium divides into a lateral and a medial limb ; the lateral divisions of the two sides unite above the free end of the clitoris, which they enclose with a hood, the *preputium clitoridis*, while the medial limbs join at an acute angle on the under side of the clitoris to form its *frenum* (**frenulum clitoridis**). Behind, the nymphæ gradually fade away by joining the inner surface of the labia majora. In the virgin, and when well developed, the medial border of the posterior ends of the nymphæ are usually connected by a slight transverse crescentic fold, the *frenum* or *fourchette* (**frenulum labiorum pudendi**) that marks the posterior boundary of the shallow navicular fossa (Fig. 1706). Both surfaces of the nymphæ are covered with delicate skin, which, on account of the protection afforded by the greater labia and constant contact with the vaginal secretions, remains moist and soft and assumes the color and appearance of a mucous membrane. The entire absence of mucous glands and the presence of numerous sebaceous follicles, on the inner as well as on the outer surface, together with the development of the nymphæ from the margin of the cloacal fossa, establish their cutaneous character. The skin covering the nymphæ externally is continuous with that of the labia majora at the bottom of the interlabial furrow ; internally the line of transition into the mucous membrane lining the vestibule follows the medial attachment of the folds which overlie the vestibular bulb. In addition to the two cutaneous layers, the nymphæ consist of an intermediate stratum of loose connective tissue, rich in blood-vessels, and containing many bundles of involuntary muscles that possess the character of erectile tissue. Hairs and fat are entirely wanting in the labia minora, but sebaceous and sweat glands are present, the latter small and scattered but most plentiful in the anterior part and in the prepuce (Webster).

FIG 1706.



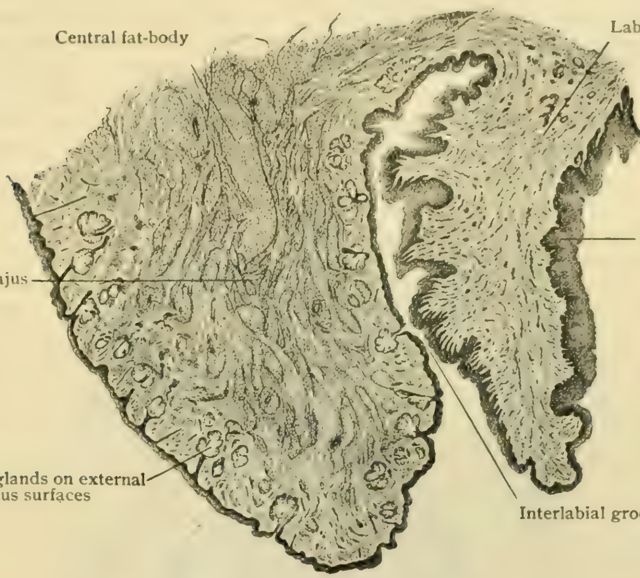
External genital organs of virgin ; labia have been separated to expose vestibule and vaginal orifice.

The **vestibule** (**vestibulum vaginae**) is the elliptical space enclosed between the labia minora, extending from the clitoris in front to the crescentic frenum behind. When the nymphæ are separated, the vestibule resembles an almond in outline, being pointed in front and broader behind. In the roof (as usually examined the floor) of this space are seen the urethral and vaginal orifices and the minute openings of the paraurethral ducts and of the canals of Bartholin's glands. The *urethral orifice* occupies a more or less conspicuous corrugated elevation (**papilla urethralis**) that lies about

2 cm. behind the clitoris and breaks the smooth mucous surface of the vestibular roof. The opening of the urethra is very variable in form, being crescentic, stellate, crucial or linear, a sagittal cleft of about 5 mm. being the most usual type. Close to the urethral orifice, at the sides or somewhat behind, lie the minute depressions marking the openings of the *paraurethral ducts* (page 1924). In young subjects, a pair of fine sagittal folds can often be traced over the roof of the vestibule from the urethral papilla to the frenum of the clitoris.

The area between the orifice of the urethra and that of the vagina is subject to considerable individual variation in size and detail owing to differences in the extent to which the lower end of the anterior vaginal column (carina urethralis) encroaches upon the vestibule. After rupture of the hymen has occurred, the vaginal entrance is surrounded by a series of irregular fimbriated projections that form the *carunculæ hymenales* which, after labor, become reduced to inconspicuous nodules. Included between the posterior margin of the hymen and the backwardly directed arching fold of the fourchette is the *fossa navicularis*, a shallow, crescentic, pocket-like depres-

FIG. 1707.



Section across the labia of very young child. × 18.

sion. This recess is best marked in the virgin, when the nymphæ are well developed, and is usually effaced after child-bearing.

Vessels.—The *arteries* supplying the labia majora are chiefly the anterior and posterior labial branches from the external and internal pudics respectively. A small twig from the superficial external pudic is distributed in the vicinity of the anterior commissure; several others from the deep external pudic end in the anterior half of the labium, while the posterior half is supplied by the posterior labial twigs from the superficial perineal branch from the internal pudic artery. Additional small twigs from the anterior terminal branch of the obturator artery are distributed to the outer surface of the labia. The nymphæ also receive their blood from the anterior and posterior labial arteries through small branches that enter the front and hind parts of the folds and assist in nourishing the mucous membrane lining the roof of the vestibule. The arteries from these various sources freely anastomose with one another as well as with adjacent vessels. While the *veins* of the labia majora in general follow the corresponding arteries, they communicate with neighboring systems, particularly with the inferior hemorrhoidal and the pelvic plexuses. The veins of the nymphæ, unusually numerous and large, present a plexiform arrangement, whereby the labia acquire the character of erectile structures. The collecting stems

join those of the labia majora, as well as communicate with the veins of the clitoris and bulb. The *lymphatics* of the labia are very numerous, notably in the more superficial parts of the folds, a half dozen or more trunks passing to the upper and medial group of inguinal lymph-nodes. The lymphatics from the nymphæ, also very numerous, join the afferents from the labia majora and end in the same inguinal nodes. Communications sometimes exist with the nodes of the opposite sides (Bruhns).

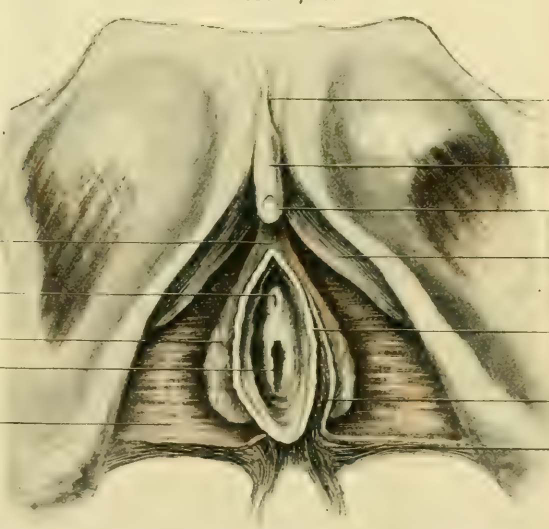
The **nerves** supplying the anterior half of the labia majora are derived from the ilio-inguinal and the genital branch of the genito-crural, while the posterior part of the labia receive filaments from the perineal branches of the pudic and the small sciatic trunks. The nymphæ are highly sensitive and receive branches from the superficial perineal nerves upon which special sensory endings are found within the subepithelial tissue.

THE CLITORIS.

The clitoris, the homologue of the penis, repeats in reduced size and modified form the chief components of the organ of the male. Morphologically considered, it consists of two corpora cavernosa, united in front into the body and separated behind into the crura attached to the pubic arch, and the imperfectly developed and cleft corpus spongiosum—known as the bulbus vestibuli and usually described as an independent organ.

The clitoris lies so buried within the subcutaneous tissue and beneath the labia that only its small conical anterior end, called the *glans clitoridis*, and the low verti-

FIG. 1708.



Dissection of urogenital triangle of female, showing clitoris and bulbus vestibuli.

cal ridge of integument over the body (**torus clitoridis**) appear when the labia are separated. The glans, about 5 mm. in diameter, is partly concealed by an annular duplicature of skin, the *preputium clitoridis*, that is free in front and at the sides, but behind is attached by a median fold, the *frenum*, continuous with the nymphæ. When exposed after removal of the labia and skin, the clitoris (using the term in the more restricted and conventional sense) is seen to consist of the small unpaired *body* (**corpus clitoridis**), from 2 to 2.5 cm. long, composed of the fused *corpora cavernosa*, and the diverging and much larger *crura*, from 3.5–4 cm. in length, that are attached to the sides of the subpubic arch, as are the corresponding parts of the penis. The crura clitoridis are, however, relatively flat and blunt. The dependent body forms a sharp bend with the diverging crura, being fixed to the lower part of the symphysis pubis by a diminutive *suspensory ligament*. Owing to its attachments to the in-

tegument and nymphæ, the position of the body and its angle undergo but slight change even in the turgescent condition of the organ. In their general structure the corpora cavernosa clitoridis, apart from their reduced size and feebler development, correspond with those of the penis, including cylinders of erectile tissue enclosed by a tunica albuginea and separated where blended by a septum. The glans, however, is composed chiefly of fibrous tissue and contains little true cavernous structure; it is, of course, not perforated by the urethra.

The Bulbus Vestibuli.—The vestibular bulb consists of two converging elongated masses of cavernous tissue, completely separated except in front, where they are connected by a narrow isthmus, the *pars intermedia*. They embrace the lower end of the vagina and the urethra, and anteriorly meet the under surface of the cavernous bodies of the clitoris. The organ, as above noted, represents the bulbar and adjoining parts of the corpus spongiosum, of which the component parts have remained ununited in consequence of the persistence of the urogenital cleft, each half corresponding to a semibulb of the united structure in the male. Each bulb, regarding the organ as paired, is a wedge-shaped body, narrow in front and broad and rounded behind, that measures from 3–4 cm. in length, where broadest from 1–1.5 cm. in width, and less than 1 cm. in thickness. Above, it rests against the inferior layer of the triangular ligament, its lower margin, somewhat medially directed, being covered by the base of the labium majus and the nympha. Behind, the medial surface is closely related to the lateral wall of the vaginal entrance, and when well developed may extend backward as far as the posterior wall of the vagina. In front, the bulb passes at the side of the urethra and joins the under surface of the clitoris. Laterally and below, it is covered by the fibres of the bulbo-cavernosus muscle. The rounded hind end meets or covers the gland of Bartholin. The two bodies together form a compressed crescentic or horseshoe-shaped complex of venous spaces, enclosed by a thin tunica albuginea, that resembles the cavernous tissue of the corpus spongiosum, although less definite in structure.

Vessels.—The *arteries* supplying the clitoris and vestibular bulb correspond with those distributed to the homologous parts of the penis, but are of smaller size. As in the male, the first branch to the cavernous tissue is the artery of the bulb (**a. bulbi vestibuli**), which enters that body near its posterior end as a short and comparatively strong vessel and joins with additional twigs to the bulb from the deep artery of the clitoris (**a. profunda clitoridis**), a branch corresponding to the urethral artery passing to the pars intermedia. Each cavernous body receives the deep branch that enters the crus and, sending a minute twig backward, traverses the cylinder of erectile tissue towards the glans, communicating with its fellow of the opposite side as well as with the dorsal artery (**a. dorsalis clitoridis**). The latter, the terminal part of the internal pudic and smallest of the vessels supplying the clitoris, pursues a course identical with that of the corresponding vessel of the penis, but is minute in consequence of the reduced dimensions of the parts supplied.

The *veins* follow the general arrangement observed in the penis, the blood being carried off chiefly by the dorsal vein and the venous channels that more closely accompany the arteries. The most important modification is the presence of the *plexus intermedius* (Kobelt), a venous complex that lies between the under surface of the corpora cavernosa, just as they begin to diverge into the crura, and the united anterior ends of the halves of the bulbus vestibuli. This plexus not only establishes connections between the blood-spaces of the corpora cavernosa and the bulbus vestibuli, but also receives tributaries from the prepuce and frenum of the clitoris, the nymphæ, and the adjacent parts of the vestibule. In addition to the stems that join the internal pudic veins, the cavernous spaces of the bulb communicate with the urethral, vaginal, and hemorrhoidal plexuses. In consequence of the connections between the plexus intermedius and the dorsal vein of the clitoris, the latter vessel is relatively of large size.

The *lymphatics* for the most part are afferents of the superficial inguinal lymph-nodes; communications exist, however, with the deeper intrapelvic paths and nodes.

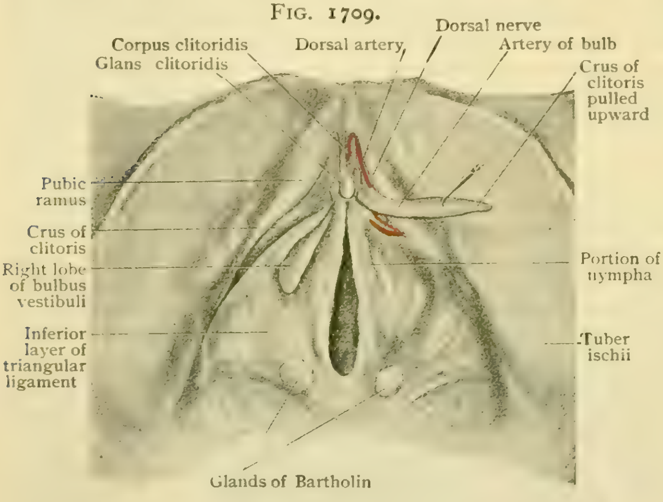
The **nerves** of the clitoris are derived and distributed in correspondence with the plan observed in the penis. They are, therefore, extensively from the sympathetic system for the walls of the blood-spaces and from the pudic nerves. The

dorsal nerve is relatively large and supplies the integument of the glans and prepuce with fibres connected with special sensory end-organs.

THE GLANDS OF BARTHOLIN.

The glands of Bartholin (**glandulae vestibulares majores**), the homologues of Cowper's glands in the male, are a pair of small organs, situated one on either side of the vaginal orifice, behind the bulbus vestibuli and about the middle of the base of the labium majus. The organ measures from 1–1.5 cm. in length and somewhat less than 1 cm. in width, and is covered on its anterolateral aspect by the bulbocavernosus muscle and, often, also by the end of the bulbus vestibuli. Its superior surface lies against the inferior layer of the triangular ligament, and its medial about 1 cm. external to the vestibule, from which it is separated by dense fibrous tissue. From the anteromedial border of the gland emerges the duct, a narrow tube, about 2 mm. in diameter and from 1.5–2 cm. long, that passes obliquely inward and forward, beneath the base of the nympha, to open in the groove between the latter and the hymen about opposite the posterior third of the lateral boundary of the vaginal orifice. The minute opening of the duct, from .5–.6 mm. wide, is often at the bottom of a small depression in the mucous membrane of the vestibule.

FIG. 1709.



Dissection of urogenital triangle of female; left lobe of vestibular bulb has been removed.

In **structure** the gland corresponds to the mucous tubo-alveolar type, the small component lobules, however, being separated by considerable tracts of fibromuscular tissue. The terminal compartments are lined with columnar epithelium containing many goblet cells. The lobular ducts unite to form the single excretory canal, which is beset with minute mucous follicles. The main duct, which sometimes exhibits ampullary enlargements, is clothed with columnar epithelium until near its termination, where its lining becomes stratified squamous in character, to correspond with that of the vestibule. The secretion of the gland is whitish in color and viscid.

Vessels.—The *arteries* supplying the gland are usually twigs given off from the bulbar branch of the internal pudic. The *veins* are tributary chiefly to the internal pudic, but also communicate with the trunks of the vestibular bulb and of the vagina. The *lymphatics* join those of the vagina and rectum that are afferents of the internal iliac nodes. It is probable that, to a limited extent, communication also exists with the paths ending in the superficial inguinal nodes.

The **nerves** are very numerous, and include sympathetic fibres and twigs from the pudic.

Development.—The glands of Bartholin first appear in embryos from 4–5 cm. long, as solid epithelial outgrowths from the lateral walls of the urogenital sinus. At first simple cylinders, they later become branched, acquire a lumen and, in embryos of from 12–15 cm. in length, begin to exhibit alveoli lined with mucus secreting cells (V. Müller). Although fully developed at birth, the glands remain small until near puberty, when they enlarge, acquiring their greatest size during the years of sexual activity. After the cessation of menstruation they gradually diminish, and are atrophic in the aged subject.

Variations.—The glands of the two sides often vary in size and may be asymmetrically placed. The ducts may be doubled and the lobules so separated that the usual gland-mass is replaced by isolated divisions. The glands are sometimes seemingly wanting on one or both sides.

PRACTICAL CONSIDERATIONS: THE EXTERNAL GENITALS.

Owing to the protected position of the vulva it is rarely wounded except from tears in childbirth. When lesions from external violence do occur, they are usually the result of falls astride hard objects, of kicks, of blows, or of wounds inflicted by horned cattle. Because of the laxity of the tissues and the free blood-supply in the labia majora large hæmatomata may collect, especially if the bulbus vestibuli is opened. Again, because of the free blood-supply and loose tissue in this region, plastic operations are commonly very successful. The hemorrhage is free, but ordinarily stops spontaneously unless the erectile tissue of the clitoris or its continuations backward, the bulbus vestibuli, is wounded.

The *lymphatics* and *veins* of the vulva pass to the groin, thus explaining the enlargement of the vulva in lymphatic obstructions in the inguinal nodes, such as elephantiasis, and in venous stasis in the same region, as in milk leg. The clitoris is especially involved in elephantiasis, either alone or as part of a general enlargement. The absorbents of the vagina pass to the pelvis. About the orifice of the vagina is a zone in which the two sets intercommunicate.

Cysts of the vulva are commonly due to retention of secretion within the glands of Bartholin. They occupy the posterior third on each side of the vaginal orifice, and project more from the mucous than from the cutaneous surface. These glands are often the seat of abscess, almost, if not always, the result of gonorrheal infection. The female urethra, running downward and forward—so that it is nearest to the vaginal wall in its upper portion—is much shorter, much less curved, relatively much wider, and—as it is not surrounded at any point by structures of such density—much more dilatable than the male urethra. In consequence of its shortness, its width, the direction of its course, and the limitation of its function to serving as a passage for urine, it is, as compared with the male urethra, infected less frequently, and its inflammation is associated with less severe symptoms, yields more readily to treatment, and gives rise to fewer complications and sequelæ,—stricture, for example, being very rare.

As a result of its dilatability it may be used as a channel for digital exploration of the bladder, or for the extraction of vesical calculi or pedunculated tumors, if small, or of foreign bodies. The dilatation should be accomplished very slowly—under an anæsthetic—and is then rarely followed by persistent paralysis. The imperfect development of the triangular (subpubic) ligament in the female and of the muscular wall of the urethra—the emptying of the canal being so facilitated by its direction, width, and shortness—explains the relative ease and safety of extreme dilatation.

A small red vascular tumor, called a *urethral caruncle*, is sometimes found protruding, usually from the posterior wall of the female urethra. It is extremely sensitive, giving rise to much pain on pressure, movement, or urination.

The vaginal process of peritoneum accompanying the round ligament, already spoken of, may reach as far as the labium majus, and may give rise to a congenital hernia or hydrocele in that part. Owing commonly to the presence of vaginal discharge, the vulvar region is frequently the seat of venereal warts. Because of the warmth, moisture, and friction to which syphilitic papules are exposed in these parts, condylomata and mucous patches are common and well marked. One of the most frequent seats of chancre in women is about the fourchette and anus, because the infected discharges of the vagina tend to run over and lodge on these structures.

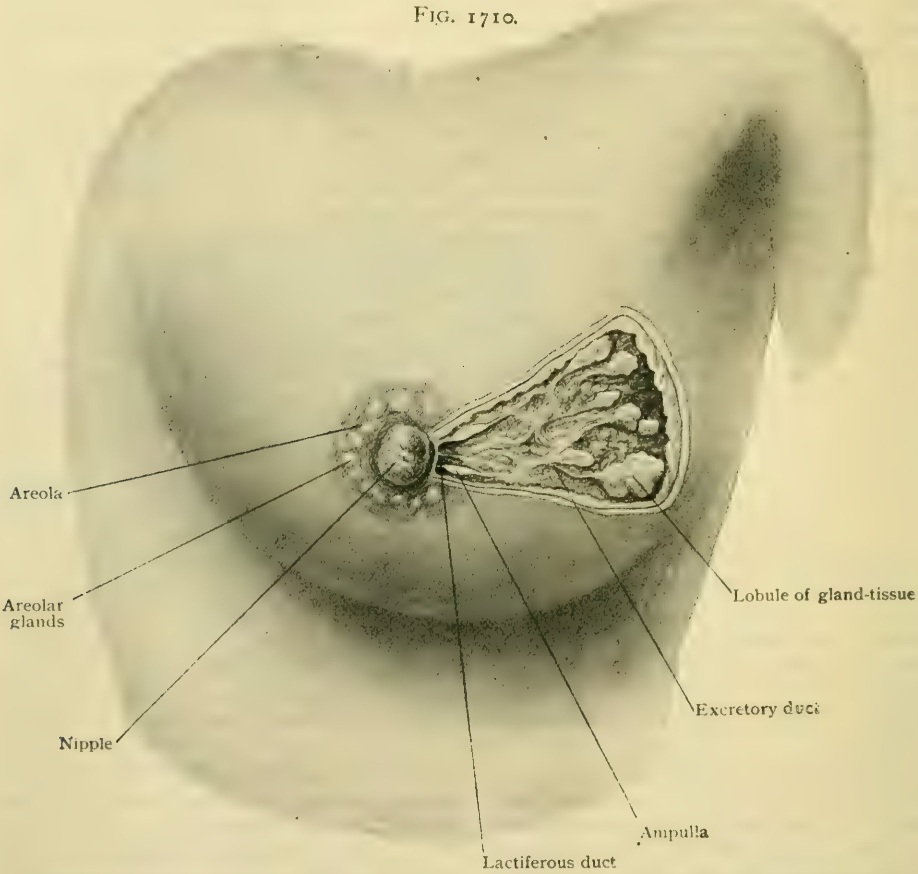
THE MAMMARY GLANDS.

Although morphologically considered they are modified cutaneous glands and developed in both sexes, the functional importance of the mammary glands (**mammae**) in the female entitles them to be reckoned as organs accessory to the reproductive apparatus. Each mamma, or breast, consists of a group of twenty or more individual

and separate glands, opening by independent ducts, that collectively constitute the true secreting organ (**corpus mammae**), as distinguished from the enveloping layer of fat and areolar tissue.

As seen in the young, well-developed subject, before the occurrence of pregnancy, the mammæ form two hemispherical projections that lie upon the thoracic wall, one on either side of the sternum, extending from the outer margin of the latter to the axillary border and from the level of the second to that of the sixth rib. The outline of the organ is not quite circular but elliptical, the horizontal diameter, from 10–12 cm. (4–4¾ in.), being about one centimetre more than the vertical. The height of the projection measures about 5.5 cm. The rounded contour of the breast depends chiefly upon the fat that forms a complete envelope for the glandular tissue,

FIG. 1710.



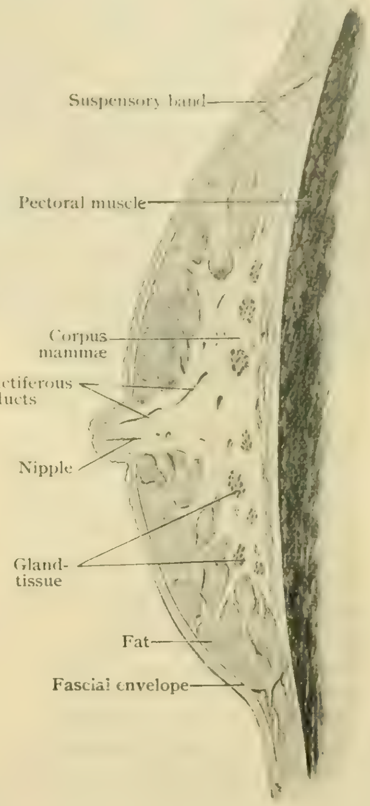
Left mamma drawn from living subject; ducts and glandular tissue have been drawn from dissection.

except beneath the nipple and, in places, on the deep muscular surface. In the young subject, in whom the gland has never enlarged in consequence of pregnancy, the secretory tissue is relatively small in amount and masked by the fat that penetrates between the lobules. The approximate summit of each breast, when firm and non-pendulous as in young women, is marked by the conical or wart-like *nipple* (**papilla mammae**), which lies opposite the lower border of the fourth rib and is pierced by the excretory canals, or *lactiferous ducts*, from the lobes. The nipple, about 1 cm. high, and marked by numerous shallow furrows, is surrounded by the *areola*, a cutaneous zone about 4.5 cm. in diameter that is modelled by minute low elevations produced by the small subcutaneous *areolar glands*, or *glands of Montgomery*, which represent isolated accessory portions of secretory tissue. Although varying with the complexion, the

pigmentation of the integument covering the nipple and areola is very slight, and hence the color of these parts is usually a rosy pink. After the earlier months of pregnancy the color of the nipple and areola changes to brown, in varying shades of intensity, which tint thereafter never entirely disappears, but becomes temporarily augmented with each pregnancy.

The mammary gland lies within the superficial fascia of the thorax, which not only forms a general investment for the organ, but also sends into it septa that materially aid in supporting the fat and glandular tissue. Local peripheral thickenings of the fascia occur above and below and assume the character of suspensory bands, those above being known as the *ligaments of Cooper*. Although for the most part separated from the underlying muscle by a layer of fascia that permits of shifting of the mamma, its deepest lobules may occupy recesses between the fasciculi of the pectoralis major.

Fig. 1711.



Sagittal section of mamma of young woman who had never borne children; hardened in formalin.

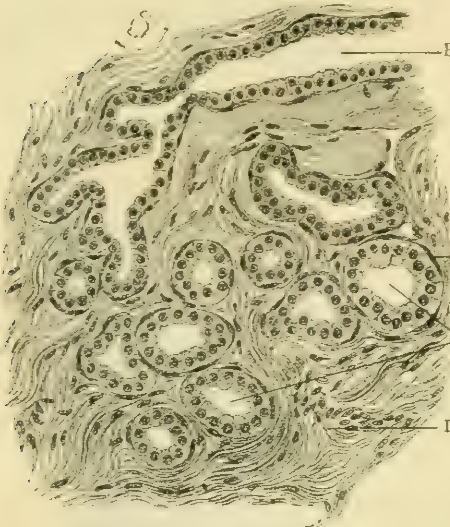
Structure.—The corpus mammæ consists of from 15–20 or more flattened pyramidal *lobes* (**lobi mammae**), each of which is a distinct gland measuring from 1.5–2 cm. The lobes are radially disposed, the groups of alveoli or lobules lying towards the periphery and the excretory ducts converging towards the nipple, upon which they open. When enlarged, as during lactation, the lobes produce irregularities in the outline and on the surface of the gland-mass that may be felt through the covering of adipose tissue. Each lobe is subdivided by connective tissue into several *lobules* (**lobuli mammae**), which in turn are made up of the ultimate divisions of the secreting tissue or *alveoli*. The latter are sacular compartments, the walls of which consist of a well-defined membrana propria, or basement membrane, lined, in the resting condition, by a double layer of cells. Those next the membrana propria are probably to be regarded as muscular in nature (Lacroix, Benda), thus emphasizing the resemblance between the mammary and sweat glands. The inner cells, the secretory elements, are cuboid or low columnar, from .005–.007 mm. high, and present the usual appearances of glandular epithelium.

During lactation the alveoli become greatly enlarged and distended and the intervening connective tissue correspondingly reduced, so that the alveoli are pressed closely together, the general appearance of the tissue often recalling that of the lung. Under such conditions the secreting cells vary with the distention of the alveoli, being low in large compartments and higher in those less expanded. The protoplasm of the cells actively engaged in the production of milk contains minute oil droplets that occupy chiefly the inner zone. As these increase in size, they press the nucleus towards the basement membrane and project into the alveolus, being separated from the lumen by only a thin protoplasmic stratum. Finally, the latter ruptures, and the oil droplets escape into the albuminous fluid that is additionally secreted by the glands and occupy the alveolus. After liberation of the oil droplets, the epithelial cell is much reduced in height, but after a time again becomes the seat of renewed accumulation of fat and the production of milk-globules. Destruction of the fat-liberating cells, therefore, does not take place.

The *excretory ducts* begin as the minute canals into which the alveoli open.

At first they are small and much like the terminal compartments of the gland and lined with a thin stratum of longitudinally disposed involuntary muscle, upon which rests a single layer of cuboid epithelial cells. The latter give place to cells of columnar type within the *lactiferous ducts* that are formed by the junction of the smaller canals. On approaching the base of the nipple, beneath the areola, each milk-duct presents a spindle-form enlargement or *ampulla* (**sinus lactiferus**), from 10–12 mm. long and about half as wide, that serves as a temporary reservoir for the secretion of the gland. Beyond the ampulla the duct narrows to a calibre of little over 2 mm., passes into the nipple, and ends, after traversing the latter parallel with the other ducts, in a minute orifice from .5–.7 mm. in diameter, at the summit of the papilla. On gaining the last-named point, the lining epithelium of the duct assumes the stratified squamous type of the adjacent epidermis. Embedded within the delicate but more or less pigmented skin that covers their exterior, the areola and nipple contain well-marked bundles of involuntary muscle, by the contraction of which the nipple becomes erect and prominent, as after the application of mechanical stimulus. Within the areola this contractile tissue forms a layer, in places almost 2 mm. thick, that encircles the base of the nipple and is continued into its substance as a net-work of bundles, between which the lactiferous ducts pass. Deeper longitudinal strands of unstriped muscle occupy the axial portions of the nipple.

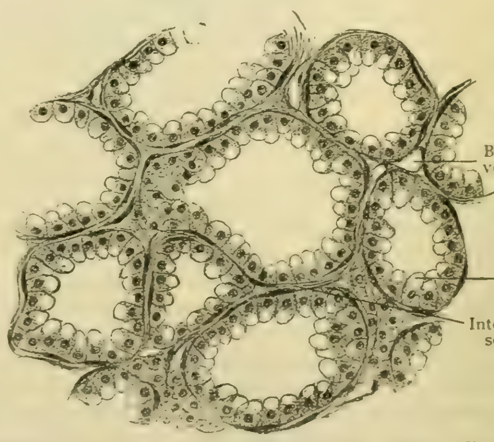
FIG. 1712.



Section of mammary gland before lactation. × 170.

Over both areola and nipple the skin is provided with large sebaceous glands, the secretion of which is increased during lactation and designed for protection while nursing. Sweat-glands are absent over the nipple, but large and modified in the vicinity of the periphery of the areola. The surface of the latter is modelled, especially towards the close of pregnancy, by low rounded elevations that indicate the positions of the subcutaneous *areolar* or *Montgomery's glands.* The latter are rudimentary accessory masses of glandular tissue, from 1–4 mm. in diameter, that correspond in their general structure with that of the mammary glands. Their ducts open by minute orifices on the surface of the areola.

FIG. 1713.



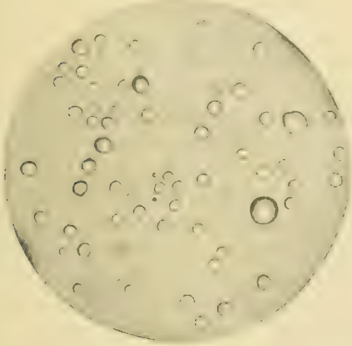
Section of mammary gland during lactation, showing distended alveoli lined with fat-bearing cells. × 170.

Milk. — The fully established secretion of the mammary gland (**lac femininum**) is an emulsion, the fatty milk-globules being suspended in a clear, colorless, and watery plasma, the variations in tint—from bluish to yellowish-white—depending upon the amount of fat. The

composition of human milk includes over 86 per cent. of water, about 3 of albuminous substances, 5.3 of fat, 5 of sugar, and less than 1 per cent. of salts. The chief morphological constituents of milk are the milk-globules (fat droplets liberated from the alveolar cells), that vary in size from the most minute spherules to those having a diameter of from .003–.005 mm. and, exceptionally, even twice as much. Their average number per cubic millimetre is something over one million (Bouchut). Whether the milk-globules are enclosed within extremely thin envelopes of casein is still uncertain. Whether the fat is actually produced within the cells, or is to be regarded as only in transit, and, likewise, whether the milk leaves the cells already emulsified, are also questions undecided.

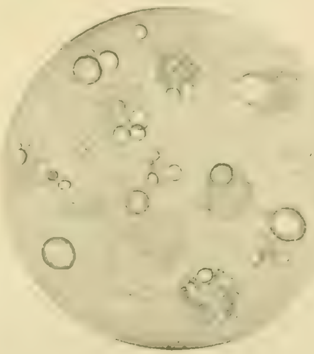
During the last weeks of pregnancy and for two or three days after its termination, the breasts contain a clear watery secretion, known as *colostrum*, that differs from milk in containing relatively little fat and numerous conspicuous bodies—the *colostrum corpuscles*—of uncertain form and size. These bodies are usually spherical, but may be irregular in outline, and measure from .012–.018 mm., although they may attain a diameter of more than .040 mm. Their protoplasm is markedly granular and often of a yellowish or reddish-yellow tint. The colostrum corpuscles are modified alveolar epithelial cells that have been cast off during the initial changes and

FIG. 1714.



Human milk. × 500.

FIG. 1715.



Colostrum, showing corpuscles and oil-drops. × 500.

expansion of the alveoli preparatory to the establishment of lactation. They again appear after this function has ended, and may continue to be expressed from the gland for months or, in exceptional cases, for even years.

Vessels.—The *arteries* supplying the mamma are principally the second, third, and fourth anterior perforating branches of the internal mammary. These vessels, in addition to their distribution to the skin and more superficial parts of the breast, send deeper twigs to the glandular tissue, which eventually break up into capillary net-works enclosing the alveoli. The lower and lateral portion of the organ receives an additional supply from the external mammary branches from the long thoracic artery from the axillary. During lactation these vessels are markedly increased in size. The *veins* follow chiefly the arteries, emptying into the internal mammary and the long thoracic. The cutaneous veins, which during lactation are enlarged and show through the delicate skin as a net-work of blue lines, in part join those accompanying the arteries and in part form vessels that take an independent course over the clavicle to become tributary to the external jugular vein. Within the areola the cutaneous veins form a plexus that more or less completely encircles the nipple and receives its blood.

The *lymphatics* of the mamma are exceptionally numerous and important. The deeper ones surround the groups of alveoli as channels that lie within the interlobular connective tissue and pass towards the surface, where they join the rich subareolar plexus. The latter also receives the collecting stems from the close cutaneous networks that drain the integument covering the nipple and areola. With the exception

of a few trunks that follow the perforating arteries and become afferents of the lymph-nodes lying along the internal mammary artery, all the lymphatics of the breast join to form two or three large trunks that pass from the lower and lateral border of the organ through the subcutaneous tissue towards the axilla to empty, sometimes united into a single stem, into the lymph-node that lies upon the serratus magnus over the third rib.

The **nerves** supplying the glandular tissue are from the fourth, fifth, and sixth intercostals, the accompanying sympathetic fibres passing by way of the rami communicantes from the thoracic portion of the gangliated cord. Their ultimate distribution may be traced to the plexuses upon the basement membrane surrounding the alveoli and, according to Arnstein, even between the secretory cells. The cutaneous nerves are derived from both the supraclavicular branches of the cervical plexus and the anterior and lateral cutaneous branches of the second to the fifth intercostals.

Development.—The arrangement of the several pairs of mammary glands possessed by a majority of the lower animals in two longitudinal rows is foreshadowed in the earliest stage of the development of these organs, so characteristic of the highest class of vertebrates (mammalia). A linear thickening of the ectoblast, known as the *milk-ridge*, appears as a low elevation that extends obliquely from the base of the forelimb to the inguinal region. Along this ridge a series of enlargements, later separated by absorption of the intervening portions of the ridge, indicates the anlage for a corresponding number of mammæ. The occurrence of a definite milk-ridge in the human embryo is uncertain, although its presence has been observed (Kallius), and the position of supernumerary mammæ suggests its influence.

In man a knob-like thickening of the ectoblast appears during the second month of fœtal life. This thickening sinks into the underlying mesoblastic tissue, which undergoes proliferation and condensation and forms an investment for the growing epithelial mass. From this envelope the fibrous and muscular tissue of the areola and nipple are derived, while the subjacent mesoblast produces the connective-tissue stroma. The ectoblastic ingrowth represents a sunken area of integument that in principle corresponds to the marsupial pouch of the lowest mammals (*monotremes*). Solid epithelial sprouts grow out from the sides of the conical or flask-shaped epidermal plug and are the first anlages of the true mammary gland, later becoming the excretory ducts. Subsequently the central part of the ectoblastic ingrowth undergoes degeneration and destruction, and what at first was an elevation now becomes a depression of the surface. From the middle of this depressed area there appears, shortly before or immediately succeeding (Basch) birth, an elevation that later becomes the nipple. Meanwhile, the epithelial duct-outgrowths penetrate the surrounding condensed mesoblastic stroma, increase in length, subdivide, and acquire a lumen at their expanded distal ends, thus giving rise to the system of ducts and the lobules of immature gland-tissue. With the further development of the latter, the surrounding mesoblastic stroma is broken up into the interlobular septa and fibrous framework of the corpus mammæ.

At birth the gland is represented by the lactiferous ducts with their ampullæ, the smaller ducts, and the immature alveoli. Quite commonly the mammary glands in both sexes are the seat of temporary activity during the first few days after birth, the breasts yielding a secretion resembling colostrum, popularly known as "witch-milk."

The mammæ remain rudimentary during childhood until the approach of sexual maturity, when they increase in size and rotundity in consequence chiefly of the deposition of fat. The full development of the true gland is deferred until the occurrence of pregnancy, when active proliferation and increase in the gland-tissue take place in preparation for its functional activity as a milk-producing organ. After lactation has ended, the mammæ undergo regression or involution, the glandular tissue being reduced in amount and returning to a condition resembling that existing before pregnancy. With the recurrence of the latter, the gland again enters upon a period of renewed growth and preparation, to be followed in time by return to the resting condition, in which the amount of glandular tissue is inconspicuous. After cessation of menstruation the mammary gland gradually decreases in size, and in advanced years the corpus mammæ may be reduced to a fibrous disc in which gland-tissue is almost entirely wanting.

Variations.—The mammæ are frequently asymmetrically developed, the left being often larger than the right. While very rarely one or both may be wanting, with or without associated absence of the nipple, increase in their number is of relatively common occurrence. The supernumerary mammæ vary greatly in the extent to which they are developed, sometimes being represented by well-formed accessory glands (*polymastia*) that may become functionating organs, but more often, particularly in the male subject, by only rudimentary nipples (*polythelia*), or even by pigmented areas suggesting areolæ. In women polythelia is usually associated with greater or less development of glandular tissue. Although the astonishing frequency (14 per cent.) of polythelia in men, as announced by Bardeleben,[1] is to be reconciled only by accepting many doubtful pigment spots as of significance, the occurrence of rudimentary supernumerary nipples in males is undoubtedly more common than formerly recognized. Exceptionally above and to the outer side, the usual position of the accessory mammæ is below and somewhat medial to the normal glands, and in general corresponds to the mammary line of the lower animals. The number of the accessory glands varies, as many as three pairs in one case, and five milk-secreting organs in another, having been observed. They are often asymmetrically placed and not uniformly developed. Comparative studies of the mammæ in the lower animals and the disposition of the supernumerary organs in the human subject, suggest the probability that man's remote ancestors normally possessed a greater number than two,[2] the occasional occurrence of the anomalous mammæ indicating a reversion to the primary condition. In addition to the supernumerary mammæ in positions anticipated by the milk-ridges, rudimentary organs sometimes occupy very unusual situations, among which have been the back, shoulder, thigh, and labium majus. Erratic mammæ are also met with among the lower animals.

PRACTICAL CONSIDERATIONS: THE MAMMARY GLANDS.

The skin covering the breast is thin and movable, with plainly visible cutaneous veins which enlarge during lactation, or in cases of mammary hypertrophy, or when obstruction due to abscess or new growth exists in the breast or in the post-mammary region. The frequent occurrence of asymmetry in size, the left breast being larger, is said (Williams) probably to be due to the fact that most mothers, being right-handed, suckle chiefly with the left breast, which is also said to be on an average heavier, more intimately associated with the pelvic sexual organs, more prone to hypertrophy, and more likely to be the seat of carcinoma or other neoplasms. The greater part of the breast lies upon the sheath of the pectoralis major muscle, on which it is freely movable, the intervening cellular tissue being extremely lax. About one-third of the gland, however, extends beyond and below the axillary border of the pectoralis major, and is in relation in the axilla with the serratus magnus and, when large, with the origins of the rectus and the external oblique. While the normal breast moves freely over the pectoral muscle, it also moves slightly with it when the muscle is contracted. Hence in inflammation of the breast, or after operation upon it or for its removal, the muscle should be kept at rest by binding the arm to the side. In testing for pathological adhesion of the breast to the pectoral sheath, it is well to move the breast in the direction of the fibres of the pectoralis major. If it is moved transversely to them, it may carry the relaxed muscle with it and no diminution of mobility will be noticeable.

In examining for growths of the breast, the normal lobes, especially if at all enlarged, may be felt through the adipose envelope and may be mistaken for tumors. To avoid this, the gland should be palpated with the flat hand, which should gently compress it against the chest wall. In this manner very small cysts or neoplasms may be recognized, as they become more resistant and more prominent than the normal gland tissue. The two breasts should be thus examined at the same time, so that any difference in their size, consistence, or sensitiveness may be detected.

The *nipple* in men and in young virgins is found over the fourth intercostal space, or over the fifth rib, about three-quarters of an inch external to the costochondral junction. In older women its position is not constant, and, of course, it varies with the degree of the enlargement, laxness, and pendency that follow pregnancy and that are common in women of tropical lands and in negresses and women of other of the lower races.

The development of the nipple may be arrested at the stage when the central part of the ectoblastic ingrowth has undergone degeneration and when a depression

[1] Anatom. Anzeiger, Bd. vii., 1892.

[2] An interesting review of the subject is given by Bonnet in Ergebrisse d. Anat. n. Entwick., Bd. ii., 1892.

exists towards the bottom of which the ducts of the mamma converge. In such cases the depression persists ; in others the areola is present, but the nipple absent. In both, while lactation may be normal, the suckling of children is impossible. The nipple may be absent or defective as a result of trauma or of disease—wounds, burns, ulcers, abscesses—during infancy.

The normal nipples of virgins or nulliparæ may be almost on a level with the areola, while those of multiparæ are often greatly elongated from the traction upon them. Temporary elongation or erection of the nipple may be caused by reflex stimulation of the unstriped muscular tissue of the skin of the nipple and areola.

Infection of the nipple is common, because, on the one hand, of the many folds of its delicate cutaneous covering, containing a number of sebaceous glands and closely connected to the underlying structures ; and, on the other, of its frequent exposure during suckling to irritation from unhealthy discharges from the child's mouth, leading to epidermic maceration and to painful erosions, fissures, and ulcers.

Atrophy of the mammary glandular elements is of normal occurrence after the menopause, the fibrous and fatty structure being also affected in many instances of noticeable withering of the breasts. In early life this condition may result from disease, or from removal of the ovaries, and become a true deformity.

Hypertrophy of the breast consists in an overgrowth of both the glandular and the fibrous elements, the latter predominating, and occurs usually between 14 and 30 years of age—the period of greatest sexual activity. Amenorrhœa and pregnancy are frequently associated with it.

Infection of the breast is usually carried through either the lymphatics or the milk ducts, most commonly during the early period of lactation ; more rarely it appears during the other notable periods of mammary physiological excitement—*i.e.*, in the newly born—the "witch-milk" period (*vide supra*)—and at puberty. In the nursing woman the presence of fissures or abrasions of the nipple predisposes to lymphatic infection. Lack of cleanliness, with fermentation or decomposition of milk and of cutaneous secretions in the folds or crevices of the nipple, favors infection in the ampullæ of the ducts.

If the superficial lymphatics are the channels of infection, suppuration in the cellulo-fatty tissue superficial to the breast may result (supramammary abscess) and, owing to the lack of tension, pointing will occur early, the course of the case will be rapid, and the constitutional symptoms relatively slight. If the deeper lymphatics or milk ducts convey the infection, suppuration occurs within the lobules (intramammary abscess) and spreads slowly from one to another through the interlobular connective tissue. As the pus is surrounded by the unyielding breast tissue and confined by the capsule of subcutaneous fascia and its septa, pain, tenderness, fever, and other constitutional symptoms are marked and the progress of the disease is slow. Occasionally, by extension from an intramammary focus, the connective tissue lying between the breast and the pectoral sheath is involved (retro, infra, or submammary abscess), but suppuration in this region is more apt to be consecutive to caries of a rib (usually tuberculous). The constitutional symptoms are less marked. The whole breast is pushed forward and made more prominent. Pointing—by reason of the effect of gravity—is apt to occur somewhere at the circumference of the breast, usually towards the inframaxillary region. Sometimes these abscesses ulcerate directly through the breast tissue to the subcutaneous area, making two cavities, one infra, the other supramammary, connected by a narrow channel, a form of Velpeau's "abcès de bouton en chemise." As the breast is thinnest along a line drawn from the sterno-clavicular joint to the nipple, it is in that region that such perforation of the gland usually occurs. As the breast—glandular and other structures, including the skin covering it—is supplied chiefly by the lateral cutaneous branches of the second to sixth intercostal nerves, pain in inflammatory or suppurative affections, or in the case of new growth, may be felt down the arm (intercosto-humeral) ; over the shoulder-blade (posterior branches of the thoracic nerves) ; down the side or along the posterior parietes of the thorax (intercostals) ; or up the neck (supraclavicular from the cervical plexus anastomosing with the second intercostal). Incisions for the evacuation of pus should be made on lines radiating out-

ward from the nipple so that the larger lactiferous ducts converging to that point may not be wounded.

Carcinoma of the breast is the most important of the diseases affecting that gland, about 85 per cent. of the neoplasms involving the female mamma being cancerous. About 99 per cent. of all neoplasms of the breast occur in the female, only 1 per cent. in the male, "illustrating the law—of which many other instances might be cited—that functionless, obsolete structures have but little tendency to take on the neoplastic process" (Williams). It begins most often in the cuboid (glandular) epithelium of the alveoli—acinous cancer; but not uncommonly in the columnar epithelium of the ducts—duct cancer. In either case it is usually at first a dense nodule of small size, growing by infiltration of the neighboring tissues. In tracing the methods of extension and dissemination from the original nodule in the gland substance, the various structural relationships must be borne in mind. The anatomical routes along which such a growth may spread, and the chief symptoms thereby produced, are as follows:

1. By way of the lymphatic vessels that empty into the lymph nodes (pectoral or anterior) overlying the digitation of the serratus magnus arising from the third rib. This is the most frequent form of lymphatic dissemination, because (*a*) these vessels include the great majority of the mammary lymphatics; (*b*) the nodes first involved in cancer are those into which is emptied the lymph from the part of the gland affected by the primary growth; and (*c*) cancer originates most frequently in the upper and outer quadrant of the breast, possibly because that area is most exposed to minor traumatism; or possibly because the alveoli are much more numerous in the peripheral than the central part of the gland, the majority of mammary neoplasms arising in the seats of the greatest development of postembryonal activity where cells still capable of growth and development most abound (Williams) —*i.e.*, in the vicinity of the alveoli. Williams calls attention to the fact that the "axillary tail" of the mamma lies close to the pectoral nodes and might be mistaken for the enlarged gland. By placing the flat of the hand or the palmar surfaces of the fingers against the inner (thoracic) wall of the axilla and moving the superficial structures to and fro, enlargement of the pectoral nodes may easily be detected.

2. From these pectoral nodes situated along the anterior border of the axilla, carcinoma may invade (*a*) the central nodes, receiving the lymph from the upper extremity, and lying on the inner side of the axillary vein, on either the superficial or deep aspect of the axillary fascia, embedded in a quantity of fat, and halfway between the anterior and posterior folds of the axilla. The inner portion of the axillary tuft of hair overlies this group of glands. The axillary fascia at this place may present an opening very similar to the saphenous opening of the thigh (Poirier, Leaf) and the nodes may occupy this. These nodes may be palpable, but if only slightly enlarged cannot readily be felt in stout persons. If no axillary opening is present and the nodes lie on the superficial aspect of the fascia, they can best be felt by pressing them against the unyielding fascia, with the arm in the abducted position; if, on the other hand, an opening is present, the arm should be adducted so as to relax the fascia, when the nodes may be recognized by pressing them against the thoracic wall. For these reasons, in examining for enlarged axillary nodes, the arm should always be placed in both these positions (Leaf). As this set of nodes is traversed by the intercosto-humeral nerve, carcinoma involving them often causes pain down the inner and posterior aspect of the arm. As they receive the lymph vessels of the upper limb, the structures in the deltoid region and down the arm may become infiltrated. Or the disease may invade (*b*) the deep axillary nodes, lying along the inner and anterior aspect of the axillary vessels, and communicating with both the pectoral and the lower deep cervical nodes; extensive implication of this group results in œdema and swelling of the upper limb, compression of the axillary vein, and in widely distributed pain in the regions supplied by the brachial plexus; (*c*) the infraclavicular (cephalic) nodes, lying just below the clavicle, between the deltoid and pectoralis major muscles and, like the deep axillary nodes, communicating below with the pectoral nodes, and above with the supraclavicular or inferior cervical nodes, the disease often reaching these latter; (*d*) the subscapular nodes, lying along the subscapular vessels and receiving lymph from the scapular region, and often, when the

central group of nodes lies on the deep surface of the axillary fascia, forming one large group with it. Involvement of these nodes with their afferent lymph vessels probably accounts for the extensive infiltration of the structures over the upper lateral and posterior aspects of the thoracic parietes occasionally seen in advanced cases.

3. The nodes at the summit of the axilla may be involved through lymph vessels passing above the pectoralis minor and through Mohrenheim's fossa without entering the pectoral nodes.

4. The anterior mediastinal glands may be invaded—especially if the inner segment of the breast is affected—by way of the lymph vessels following the perforating arteries and emptying into the nodes along the internal mammary artery. In this manner, as well as by direct extension through the inframammary tissue, the pectoral fascia and muscles, and the chest wall, the pleura and lung may become involved. Other symptoms due to mediastinal growth have been described in relation to that region (page 1833).

5. The free communication in the subareolar plexus between the glandular lymphatics, deep and superficial, (paramammary) and the subcutaneous and thoracic lymphatics, together with the connection established between the periglandular tissue below and the skin above by the ligaments of Cooper (suspensory ligaments), explains the frequency with which mammary carcinoma extends to the overlying skin. As a result of its infiltration the latter becomes dense, inelastic, brawny, dusky, and adherent. It cannot be picked up between the thumb and finger in a fold; and often quite early and before it has become adherent, and as a result of contraction of the growth pulling on the fibrous bands uniting it to the deeper parts, it is drawn into a number of little depressions or dimples like those on the skin of an orange. When such infiltration is diffuse and spreads largely through the subcutaneous net-work of lymph vessels, the condition known as *cancer en cuirasse* is produced. In the later stages ulceration, infection, hemorrhage, and foul discharge are frequent results of the cutaneous involvement.

6. If the growth is central it may extend to the lactiferous ducts or to the periacinous tissue continuous with that surrounding the ducts, and through its own or their cicatricial contraction it may depress or retract the nipple or pull it so that it deviates from its normal direction. This is not so valuable a symptom as the dimpling of the skin above described, as it may be caused by injury or by chronic disease, such as abscess, tubercle, or mastitis. Moreover, it may not be present if the growth is peripheral.

7. The carcinoma may extend through the lymph communications between the gland and the underlying connective tissue and pectoral fascia and muscle, so as to become fixed to or incorporated with those structures, the breast losing much of its mobility, especially in a direction parallel with the pectoralis major fibres. It may thence continue through the thoracic wall and invade the pleural or mediastinal cavity directly.

8. Through the intercommunication of the lymph system of the two breasts through the subcutaneous thoracic lymphatics, cancer of one breast may extend to the other (Moore), or to the glands of the opposite axilla (Volkmann, Stiles), or to the glands of both axillæ (Scarpa, Cooper; quoted by Williams).

9. General dissemination of the cancerous disease may also take place through detached cells or particles (emboli) from the primary growth entering the blood stream. The liver is the organ most frequently affected by metastasis in cases of breast cancer. The bones, the lungs, and the pleuræ come next, but almost no organ or structure of the body is exempt.

In *removal of the breast* the following anatomical points should be borne in mind: (*a*) The intimate connection between the skin and the gland itself by means of lymph- and blood-vessels, by the suspensory ligaments, and by glandular processes accompanying or contained within these ligaments (Stiles), shows the necessity for free sacrifice of the skin overlying the breast.

(*b*) The irregular shape of the breast, which has two extensions that frequently reach into the axilla, and one that reaches to or overlaps the border of the sternum, and not uncommonly similar processes that spring from other parts of the surface of

the gland and radiate in the paramammary fatty tissue (Williams) emphasizes the need for incisions that shall permit the removal of all such portions of possibly diseased glandular tissue.

(*c*) The usual defect in the retroglandular fatty envelope, bringing the glandular lobules into intimate relation with the pectoral fascia and muscle (Heidenhain), facilitates extension of the disease in that direction and indicates the free removal of the pectoralis major in most cases.

(*d*) The lymphatic distribution (*vide supra*) supplies the same indication as to removal of the greater pectoral and—to a lesser degree—as to the lesser pectoral also. It, of course, points unmistakably to the need for thorough cleaning out of the axilla. In doing this it is well to remove the chain of lymphatic nodes—pectoral, central, deep, subscapular, etc.—in one piece, not only because it minimizes the risk of infection of healthy structures during the operation (Cheyne), but because if the clavi-pectoral fascia (suspensory ligament of the axilla) and the axillary fascia, together with the greater part of the pectoralis minor muscle (on account of the continuity of its sheath with the clavi-pectoral fascia), are removed in one piece, the groups of nodes enumerated above and embedded in them will be removed also (Leaf). To this there are three exceptions: (1) a node of the subscapular group sometimes projects backward and is found between the teres minor and infraspinatus muscles; (2) some nodes of the infraclavicular group may lie to the outer side of the axillary vein, and when this is so, as the suspensory ligament is stripped off the inner side these glands would remain behind; (3) the cephalic node would not be reached during the removal in one piece of the ligament and axillary fascia with their contained groups of nodes. Of course all these nodes should be sought for and removed separately (Leaf).

(*e*) The most important blood-vessel in danger during the operation is the axillary vein (page 888), made somewhat more prominent—together with the artery and the brachial plexus—when the arm is raised and the head of the humerus is made to project into the axilla. These structures normally lie on the outer wall of the axilla, but may be so embedded in a mass of cancerous tissue as to be difficult of recognition. On the posterior aspect of the axilla the subscapular vessels and (in close proximity to the subscapular nodes) the long subscapular nerve supplying the latissimus dorsi muscle should be avoided. The inner (thoracic) wall of the axilla is the region in which the dissection may be conducted with the greatest freedom, the posterior thoracic nerve running almost vertically downward in close contact with the outer surface of the serratus magnus muscle to which it is distributed. The arteries met with or divided in the course of the operation are (1) the pectoral branches of the acromial thoracic; (2) the alar thoracic; (3) the long thoracic (external mammary) running along the lower border of the pectoralis minor muscle; (4) lateral branches from the second, third, and fourth intercostal arteries; and (5) anterior perforating branches of the internal mammary artery, emerging at the second, third, and fourth intercostal spaces. The vessels in the last two groups are normally small, but by enlarging during the growth of a carcinoma and by retracting after division to beneath the surface of the chest-wall, they are sometimes slightly troublesome during operation.

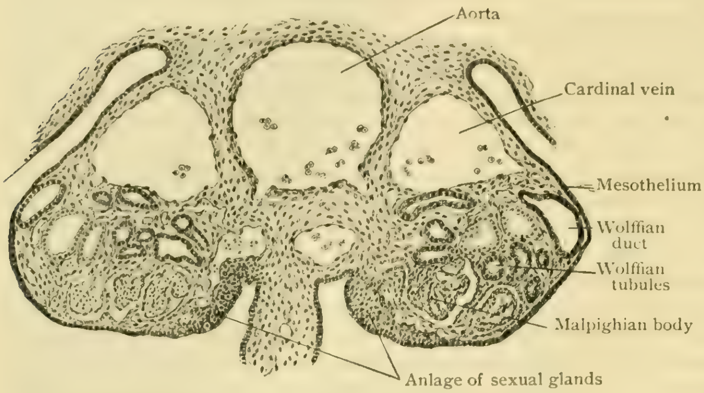
DEVELOPMENT OF THE REPRODUCTIVE ORGANS.

The development of the internal organs of reproduction includes two distinct but closely related processes, the one leading to the formation of the sexual glands, the testes or ovaries, and the other to the provision of the canals for the conveyance and temporary storage of the products of these glands. Provision of the excretory canals is accomplished by the secondary changes and further growth of parts of the Wolffian tubules and ducts in conjunction with two additional canals—the Müllerian ducts.

References to the preceding account of the Wolffian body (page 1935) will recall the constitution of the latter as including a series of transverse tubules opening into a common longitudinal duct, and, further, that the Wolffian tubules comprise an anterior sexual and a posterior excretory group.

During the development of the Wolffian body, or mesonephros, a second tube, the *Müllerian duct*, is formed within a linear thickening, the *genital ridge*, that appears upon the ventro-lateral surface of the Wolffian body. Near the cephalic end of the latter, an evagination of the lining of the body-cavity into the genital ridge occurs, by the continued proliferation and downward growth of the cells of which the evagination is converted into a tube—the Müllerian duct. This tube communicates directly with the body-cavity by means of its trumpet-shaped cephalic extremity, extends parallel with and closely related to the Wolffian duct and, later, below reaches the urogenital sinus. The converging lower segments of the two Wolffian and the two Müllerian ducts are embedded within a median mesoblastic band, the *genital cord*, that represents the continuation of the fused genital ridges of the two sides. Within the genital cord the Müllerian ducts lie in the middle, closely applied to each other, with one Wolffian duct on each side (Fig. 1649).

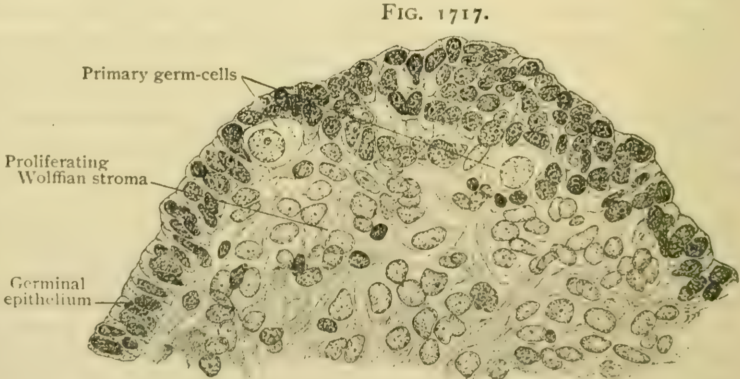
FIG. 1716.



Portion of cross-section of early human embryo, showing first appearance of sexual glands within germinal ridges. × 60.

The *development of the sexual glands* begins about the time that the Müllerian ducts are forming, as a linear thickening of the mesothelium and underlying mesoblastic stroma, situated, however, on the median surface of the Wolffian body (Fig. 1716). Over this raised area, the *germinal ridge*, the character of the primary peritoneum changes, its cells becoming taller and undergoing proliferation. Very early among the increasing elements appear specialized cells distinguished by their large size, clear protoplasm, and conspicuous nucleus. These are the *primary germ-cells*, which later become the primordial ova or sperm-cells, according to sex. For a time this cannot be determined, since in this *indifferent stage* of the sexual gland specialization has not yet progressed sufficiently to make differentiation possible. The distinctive features of both sexes, therefore, are acquired by farther development of a neutral sex-type in which the indifferent sexual glands, the Wolffian tubules, the Wolffian and the Müllerian ducts are the chief components. In view of the recent investigations on the germ-cells, it is probable that the peculiar or sex-chromosomes have much to do with the determination of sex, which differentiation, therefore, dates from the time of fertilization.

FIG. 1717.

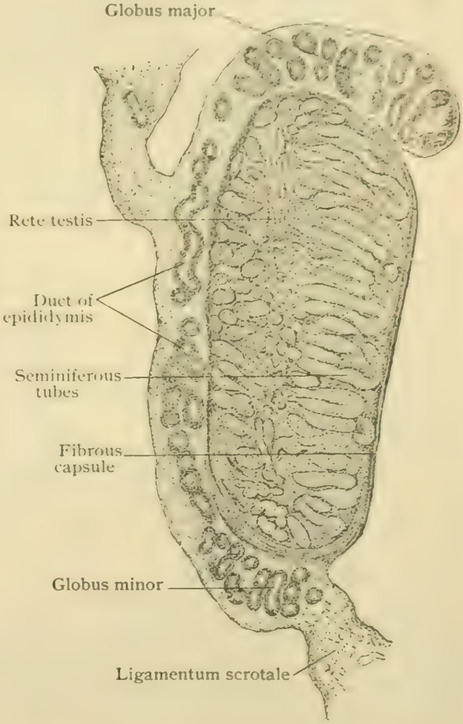


Cross-section of germinal ridge of young human embryo, showing early differentiation of primary germ-cells. × 500.

Differentiation of the Male Type.—The development of the testis from the indifferent sexual gland includes the invasion of the proliferated mesothelial cells of

the germinal ridge by the underlying mesoblastic stroma, whereby the epithelial mass becomes broken up into cylinders and cords that extend into the subjacent stroma. The cell-cords are composed of two kinds of elements, the numerous chief epithelial cells and the larger *sperm-cells*, the direct descendants of the indifferent primary germ-cells, which they embrace. About the fifth week a layer of mesoderm insinuates itself between the superficial and deeper portions of the epithelial mass, thereby separating a peripheral zone. This ingrowth results in the formation of a robust fibrous envelope, the tunica albuginea, around the entire testis, while the separated mesothelial layer differentiates into the serous covering. The cell-cords become subdivided by the ingrowth of the mesoblastic stroma into smaller spherical masses, which subsequently are converted into the seminiferous tubules, while from the stroma are supplied the interlobular septa and the intralobular supporting tissue. About the sixth week additional cell-cords grow into the young testis from the adjacent Wolffian tubules. These ingrowths invade the attached border of the testicle and become the *medullary cords*, which are so disposed that each comes into relation with one of the spherical epithelial cell-masses. Although both the latter and the medullary cords are solid, the later relation of the secreting tubules of the gland to the excretory channels is thus foreshadowed, since from the ingrowths from the Wolffian tubules are derived the straight tubules and those of the rete testes. The farther differentiation of the seminiferous canals, which, as well as the medullary cords, are without lumen until near puberty, proceeds from the growth and branching of the cell-masses, the cells of which become the epithelium of the tubules. The latter are enclosed by an investment of condensed mesoblastic stroma continuous with the supporting tissue and framework of the gland. At the approach of sexual maturity the primary sperm-cells within the tubules proliferate and become the spermatogonia, while from other epithelial elements are derived the Sertoli cells. The rôles played by these elements in the production of the spermatozoa are described under Spermatogenesis (page 1945).

FIG. 1718.



Longitudinal section of developing testicle. × 20.

Coincidently with the growth of the testis the Wolffian body atrophies, with the exception of some of its tubules and duct, which increase and, in conjunction with the medullary cords also derived from the mesonephros, establish the elaborate excretory passages of the sexual gland. From the Wolffian tubules are developed the coni vasculosi and the ductuli efferentes, while the Wolffian duct gives rise to the tube of the epididymis, the vas deferens, and, as a secondary outgrowth, the seminal vesicle. The caudal group of mesonephric tubules are represented in both sexes by rudimentary structures, which in the male are the paradidymis and the vasa aberrantia. The appendix of the epididymis, or stalked hydatid, probably also owes its origin to the Wolffian duct.

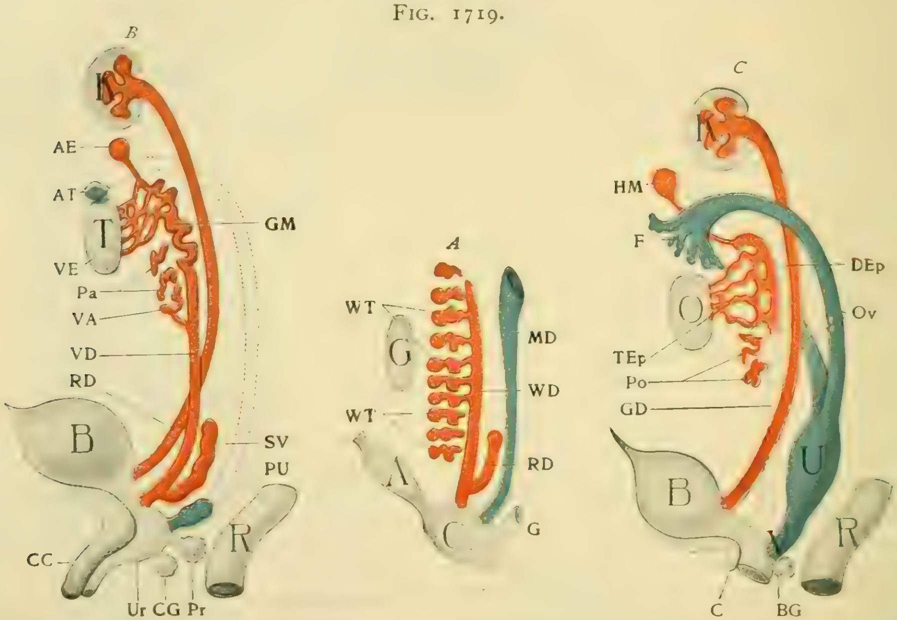
Although, as is evident from the foregoing, the Wolffian tubules and duct are largely concerned in the development of the generative tract in the male, the Müllerian duct is not without representation, since its two extremities persist. The upper (after migration lower) end remains as the appendix of the testis, and the lower, fused with its fellow, is seen as the prostatic utricle, which, therefore, is the homologue of the vagina and, possibly, the uterus. In exceptional cases, where it

persists, the intervening portion of the Müllerian duct is represented by Rathke's duct. Since the prostate gland arises as an outgrowth from the urogenital sinus (page 1979), it has no genetic relation with the seminal ducts.

Descent of the Testes.—The development of the sexual glands, in both sexes, is attended with conspicuous migration from their original position on either side of the upper two lumbar vertebræ, opposite the lower pole of the kidney. In the case of the testis, this migration is so extensive that by birth the organ usually has passed through the abdominal wall and entered the scrotum, having completed its so-called descent.

Certain peritoneal folds (mesenteries) and fibro-muscular bands (ligaments) merit brief description, since they are more or less concerned in the migration of the sexual glands. The Wolffian body is enclosed and attached to the posterior body-wall by a fold (*mesonephridium*), of which the upper elongated end is continued to the

FIG. 1719.



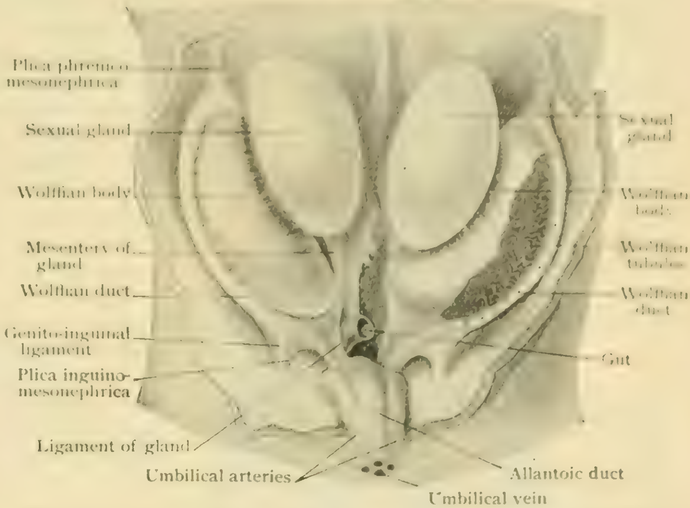
Diagrams illustrating differentiation of two sexes from indifferent type. *A, Indifferent:* G, sexual gland; WD, Wolffian duct; WT, WT, groups of Wolffian tubules; MD, Müllerian duct; RD, renal diverticulum; C, cloaca; G, gut; A, allantois. *B, Male:* T, testicle; VE, vasa efferentia; GM globus major; VD, vas deferens; Pa, paradidymis; VA, vas aberrans; SV, seminal vesicle; AT, appendix testis; AE, appendix epididymidis; B, bladder; PU, prostatic utricle; Pr, prostate; Ur, urethra; CG, Cowper's gland; CC, corpus cavernosum; R, rectum; RD, renal duct; K, kidney. *C, Female:* O, ovary; Ov, oviduct; F, fimbria; U, uterus; V, vagina; DEp, duct of epoophoron; TEp, tubules of epoophoron; Po, paroophoron; HM, hydatid of Morgagni; GD Gartner's duct; BG, Bartholin's gland; C, clitoris; K, kidney; R, rectum. (*Modified from Wiedersheim.*)

diaphragm (*plica phrenico-mesonephrica*) and the lower to the abdominal wall in the inguinal region (*plica inguino-mesonephrica*). The early sexual gland is also provided with a mesentery (*mesorchium* or *mesovarium*), that above and below is continuous with folds that pass from the upper and lower poles of the gland to the mesentery of the mesonephros. Within the inferior plica, of the two much the better marked, lies a fibro-muscular strand (the *ligament of the testis* or *ovary*), that below is attached at first to both the Wolffian and Müllerian ducts. Later, owing to the atrophy of the one or the other of these ducts, according to sex, the ligament of the testes remains connected with the Wolffian duct and the ligament of the ovary with the Müllerian duct.

A second band of muscular tissue appears within the lower part of the inguino-mesonephric fold, and has its upper attachment also to the Wolffian and Müllerian ducts at a point about where they receive the insertion of the ligament of the testes or ovary. The lower end of the band blends with the subperitoneal tissue of the anterior abdominal wall in the vicinity of the future abdominal ring. This band, the *genito-*

inguinal ligament, corresponds with the gubernaculum testis in the male and with the round ligament of the uterus in the female. In the former it is not directly attached to the testis, but only through its ligament, the point of attachment later corresponding to the origin of the vas deferens from the epididymis.

Fig. 1720.



Wolffian bodies and sexual glands of human embryo of about six weeks (17 mm. long). × 15. (*Modified from Kollmann.*)

The testicle begins its descent during the second fœtal month, coincidently with commencing atrophy of the Wolffian body, and, under the influence and guidance of the genito-inguinal ligament, by the end of the third month reaches the anterior abdominal wall in the vicinity of the later internal abdominal ring. This position it retains until the close of the sixth month, when it enters upon its final descent.

Meanwhile, the musculo-fascial layers of the abdominal wall undergo evagination, resulting in the production of a shallow pouch, the *inguinal bursa*, into which a sac of peritoneum, the *processus vaginalis*, extends, together with the closely associated genito-inguinal ligament. The inguinal bursa, in turn, sinks into the shallow scrotal pouch that has independently developed as an integumentary fold. The wall of the bursa contains the constituents that later differentiate into the coverings proper of the spermatic cord and testicle—the intercolumnar, cremasteric, and infundibuliform fasciæ. Its muscular fibres, prolonged from the internal oblique and transversalis layer, correspond with the cremaster, and surround the genito-inguinal ligament.

Owing to the thickening of the lower end of the latter, a slight elevation appears on the floor of the bursa, which thus seemingly becomes pushed up towards the testis to form the rudiment of what in some animals becomes a well-marked projection, the *conus ingualis*, but in man always remains insignificant. In consequence of these changes, during the fourth month the testis is displaced upward and its descent temporarily interrupted.

Fig. 1721.

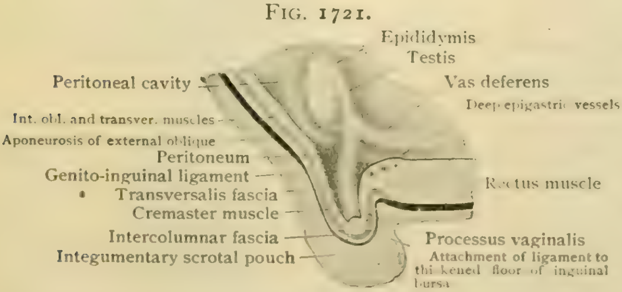


Diagram showing early stage in descent of testicle. (*After Waldeyer.*)

About the beginning of the seventh month, the final descent of the testicle is inaugurated with deepening of the bursa and downward extension of the peritoneal pouch, accompanied by the now thickened and shortened genito-inguinal ligament. Although shortening of the latter, together with the pull exerted by the cremasteric fibres, plays an active rôle in drawing the testicle through the abdominal wall and into the scrotum, these factors are undoubtedly supplemented by forces resulting from the growth and expansion of the pelvis and inguinal regions.

The processus vaginalis reaches the bottom of the scrotal sac in advance of the

testicle, which, drawn from its mesentery (mesorchium), descends outside and behind the peritoneal pouch that later constitutes its partial serous investment, the tunica vaginalis. After the descent is completed, usually shortly before birth, but sometimes not until afterward, the tubular upper segment of the peritoneal sac closes normally during the early months of childhood. This closure takes place first in the vicinity of the internal abdominal ring and in the middle of the tube, passing upward towards the ring and downward to within a short distance of the sexual gland. The occluded portion of the vaginal process is later represented by a small fibrous band (*ligamentum vaginale*) that extends from the internal abdominal ring above, through the inguinal canal and for a variable distance down the spermatic cord, sometimes, although not commonly, as far as the tunica vaginalis. When the processus vaginalis fails to close, as it occasionally does in man and always in certain animals, as the rat, in which descent and retraction of the testis periodically occur, the serous sac surrounding the testicle communicates throughout life with the peritoneal cavity, a condition favorable to the production of hernia. With the obliteration of the lumen of the processus vaginalis, an inguinal canal, in the sense of a distinct tube, disappears, the spermatic duct and associated vessels and nerves, that necessarily share in the migration of the sexual gland into the scrotum, passing between the muscular and fascial layers of the abdominal wall embedded in connective tissue. The remains of the shrunken genito-inguinal ligament, or gubernaculum, are represented by a fibro-muscular band, the *scrotal ligament*, that connects the lower end of the epididymis to the scrotal wall (Fig. 1650).

FIG. 1722.

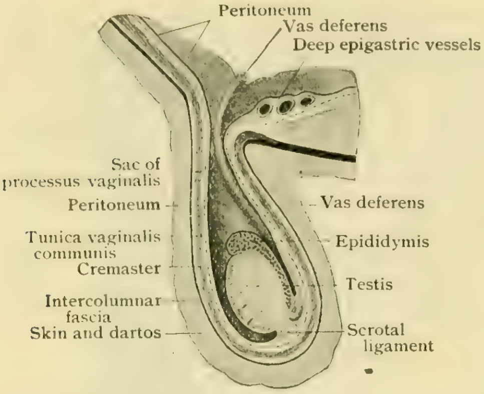


Diagram showing relations of descended testicle to processus vaginalis, which still freely communicates with peritoneal sac of abdomen. (*After Waldeyer.*)

Descent of the testicle may be imperfectly accomplished, so that the gland, failing to reach the bottom of the scrotal sac, may be arrested within the inguinal canal or spermatic cord, or permanently retained within the abdomen, a condition known as cryptorchism, usually leading to atrophy of the gland. Associated with faulty descent may be anomalous situation, the testis lying beneath the integument near the external abdominal ring, in the thigh, or in the perineum. After descent the axis of the testicle may be abnormally directed, the gland assuming a transverse, rotated, or even inverted position.

Differentiation of the Female Type.—Development of female internal reproductive organs proceeds along the same lines as in the male, the ovary being differentiated from the indifferent sexual gland and the genital canals from the Müllerian and Wolffian ducts.

Differentiation of the ovary has been described in connection with that organ (page 1993). That of the Fallopian tubes, uterus, and vagina results from further growth, fusion, and modification of the Müllerian ducts. Lower segments of the latter, below the attachment of the ligament of the ovary (page 2040), undergo fusion and form the uterus and vagina. Their upper segments remain unfused and become Fallopian tubes. Details of these changes are given under the respective organs.

FIG. 1723.

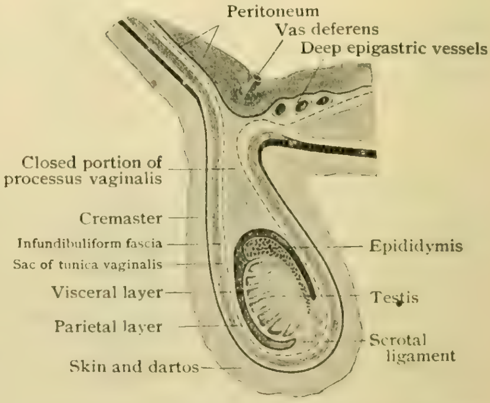
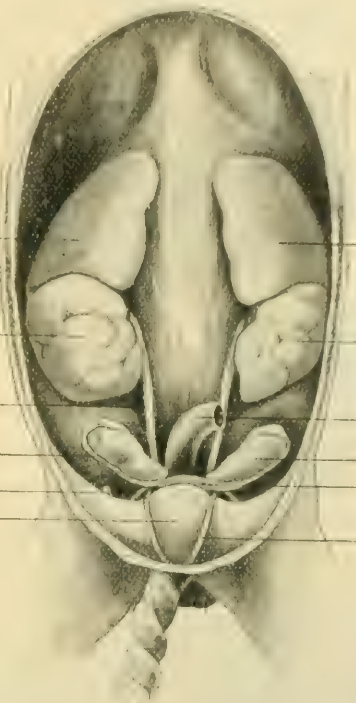


Diagram showing relations of testicle to serous membrane after upper part of processus vaginalis has closed, its lower part persisting as tunica vaginalis.

In the female the Wolffian tubules and duct play a subordinate rôle, remaining to form rudimentary organs, the epoophoron (page 2000), the paroophoron (page 2002), and, when the Wolffian duct persists, the duct of Gartner (page 2001). The broad ligament is formed by the enlargement of the primary peritoneal fold containing the Müllerian and Wolffian ducts.

Descent of the Ovary.—The primary position of the ovary, at the side of the upper two lumbar vertebræ, corresponds with that of the testis, the sexual gland, as in the male, undergoing migration in order to gain its permanent location. In the case of the ovary, however, this migration is much more limited, notwithstanding the provision of the same equipment for descent as in the male, including the genito-inguinal ligament, inguinal bursa, peritoneal evagination, and even cremaster muscle. The gland fails to reach the internal abdominal ring and remains until birth at the brim of the pelvis in consequence of the large size of the uterus in relation to the small pelvis. When the growth and expansion of the latter have provided additional capacity, as the uterus sinks to its definite position, the ovaries, attached by their ligaments and oviducts, follow into the pelvis.

FIG. 1724.



Sexual organs of female fœtus of third month, showing ovaries still undescended and bicornate uterus. × 2.

The genito-inguinal ligament becomes the round ligament of the uterus, the lower end of which is attached to the subcutaneous tissue of the labium majus at the external abdominal ring. These relations are foreshadowed by the close association of the lower end of the fœtal ligament to the bottom of the inguinal bursa and the wall of the processus vaginalis. The lumen of the latter usually disappears, but in exceptional cases may persist as the canal of Nuck (page 2015). Associated with this condition, occasionally the ovary more closely imitates the descent of the testicle by passing into or even through the inguinal canal.

DEVELOPMENT OF THE EXTERNAL ORGANS.

The external genital organs develop from an indifferent type and, until the beginning of the third month, do not exhibit the distinguishing characteristics of either sex. While the differentiation of the sexual glands occurs early, in embryos of 22 mm. length, not until about the ninth week, in embryos of 31 mm., is sex determinable by inspection of the external organs. The earliest trustworthy external indication of sex is the downward curve of the growing genital tubercle, later the clitoris, that takes place at this time in the female (Herzog).

About the fifth week, before the rupture of the cloacal membrane, the tissue bordering the external cloacal fossa in front grows forward into a rounded projection, the *genital tubercle.* The latter rapidly increases in size and differentiates into a distal knob-like end and a bulbous ventral expansion at its base which becomes divided by a groove that extends along the under surface of the genital tubercle. The lips of this groove elongate into the *genital folds* that lie on either side of the opening into

the urogenital sinus that appears when the cloacal membrane ruptures. Somewhat later, about the ninth week, a pair of thick crescentic swellings, the *outer genital*, or *labio-scrotal folds*, make their appearance on either side of the genital tubercle.

In the female, in which the original relations are largely retained, the genital tubercle grows slowly and is converted into the glans and body of the clitoris, while the inner genital folds become the nymphæ and the outer ones the labia majora. The urogenital sinus remains as the vestibule and its opening as the vulvar cleft. The wedge of tissue between the posterior margin of the latter and the anus becomes the perineal body.

A description of the development of the glands of Bartholin is given in connection with the consideration of these organs (page 2026).

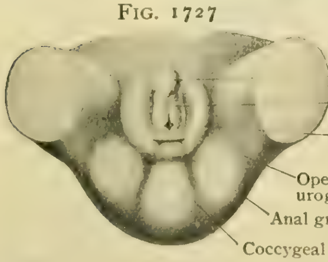
FIG. 1725.

Surface markings of cloacal region of human embryo of seventeen days (Fig. 1644). × 12. (*Keibel.*)

FIG. 1726.

External genitals of human embryo of about twenty-seven days. (*Kollmann.*)

FIG. 1727



Indifferent stage of external genitals of human embryo of thirty-three days (Fig. 1647). × 8. (*Keibel.*)

In the male the modifications leading to the fully differentiated external organs are more pronounced in consequence of the formation of the urethra.

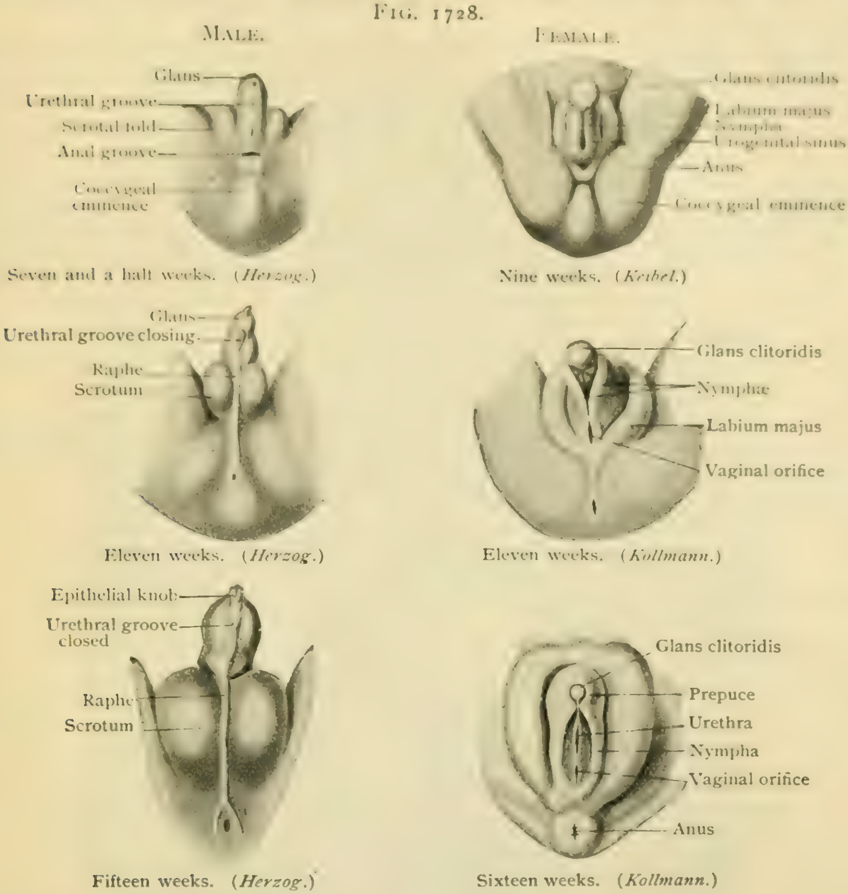
The genital tubercle rapidly increases in size, becomes somewhat conical and differentiated into the glans and shaft of the penis. The parts of the outer genital folds behind the penis soon become enlarged, rounded, approach each other, and, finally, unite along a line afterward indicated by the median raphe, so that in embryos of 45 mm. length the scrotum is already well defined. According to Herzog,[1] the development of the urethra proceeds from an epithelial ridge that appears on the cloacal membrane and extends forward along the under surface of the genital tubercle towards its distal end. This ridge sinks into the mesoblastic tissue of the elongating genital tubercle as a narrow longitudinal strand (urethral septum), and later becomes partially divided by a superficial furrow, the *urethral groove*, the lips of which correspond to the inner genital folds. In consequence of the cleavage of the posterior third of the epithelial ridge, the cloacal membrane is ruptured and communication established with the urogenital sinus by means of a small canal that opens into the urethral groove. As the latter grows farther forward towards the glans, approximation and fusion of its edges occur behind, whereby the groove is gradually converted into the urethral canal. In this manner the distal opening of the urethra is carried forward until its definite position on the glans is reached. Arrested development or fusion of the edges of the urethral groove results in defective closure of the canal, a condition known as hypospadias (page 1927).

The formation of the prepuce begins as a thickening and ingrowth of the surface epithelium at the bottom of an annular groove that separates the glans from the body of the penis. From this thickening the epithelium grows backward, invading the young connective tissue as a narrow wedge-shaped mass that encircles the glans, except below, where it is incomplete and the frenum later appears. In this manner an annular fold, the prepuce, is defined around the base of the glans that later, just before or shortly after birth, becomes free by the partial solution of the intervening solid epithelial stratum and its conversion into the preputial sac.

[1] Archiv f. mikros. Anatom., Bd. lxiii., 1904.

The developmental relations of the various parts of the urogenital system to the embryonal structures, as well as their morphological relations to one another in the two sexes, are shown in the diagrams (Fig. 1719) and accompanying table :

FIG. 1728.



Development of external generative organs.

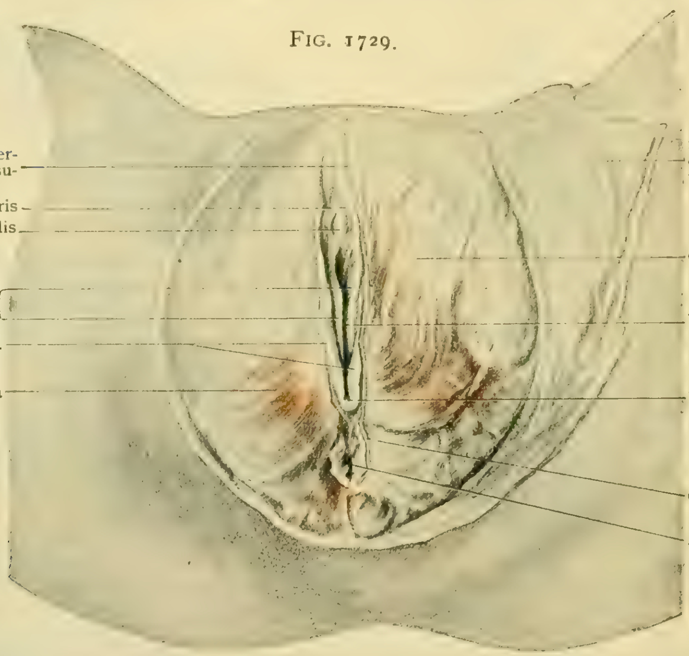
Male	Indifferent Type	Female
Testis	*Sexual gland*	Ovary
Coni vasculosi and ductuli efferentes	*Wolffian tubules* (*sexual group*)	Short tubules of epoophoron
Paradidymis		Paroophoron
Duct of epididymis	*Wolffian duct*	Main tube of epoophoron
Vas aberrans		Gartner's duct, when persisting
Seminal vesicle		
Appendix of epididymis	(*upper end*)	Hydatid of Morgagni
Appendix of testis	*Müllerian duct*	Oviduct
		Uterus
Prostatic utricle		Vagina
Ureter	*Renal outgrowth*	Ureter
Pelvis and collecting tubules of kidney	*from Wolffian duct*	Pelvis and collecting tubules of kidney
Bladder	*Lower segment of allantois and part of cloaca*	Bladder
Prostatic urethra	*Urogenital sinus*	Urethra and vestibule
Prostate gland	(*outgrowths from wall*)	Paraurethral tubes
Cowper's gland		Bartnolin's gland
Penis	*Genital tubercle*	Clitoris
Lips of urethral groove	*Genital folds*	Labia minora
Scrotum	*Labio-scrotal folds*	Labia majora

THE FEMALE PERINEUM.

The structures closing the pelvic outlet in the female correspond with those found in the male, modified, however, by the presence of the urogenital cleft and the small size of the clitoris.

Owing to the greater divergence of the bony boundaries of the subpubic angle and the increased distance between the ischial tuberosities, the width of the lozenge-shaped perineal space (when the limbs are separated) is somewhat greater in the female. As in the male (page 1916), the perineal region is divisible into a posterior *rectal* and an anterior *urogenital* triangle by an imaginary transverse line drawn between the anterior borders of the ischial tuberosities. Distinction must be made between the term "perineum," as above used, to indicate the entire region, and when applied in a restricted sense to the bridge separating the anal and vulvar orifices. Reference to sagittal sections (Fig. 1700) shows that this superficial bridge forms the

FIG. 1729.



Superficial dissection of female perineum; on right side skin only has been removed; on left, superficial layer of superficial fascia has been reflected.

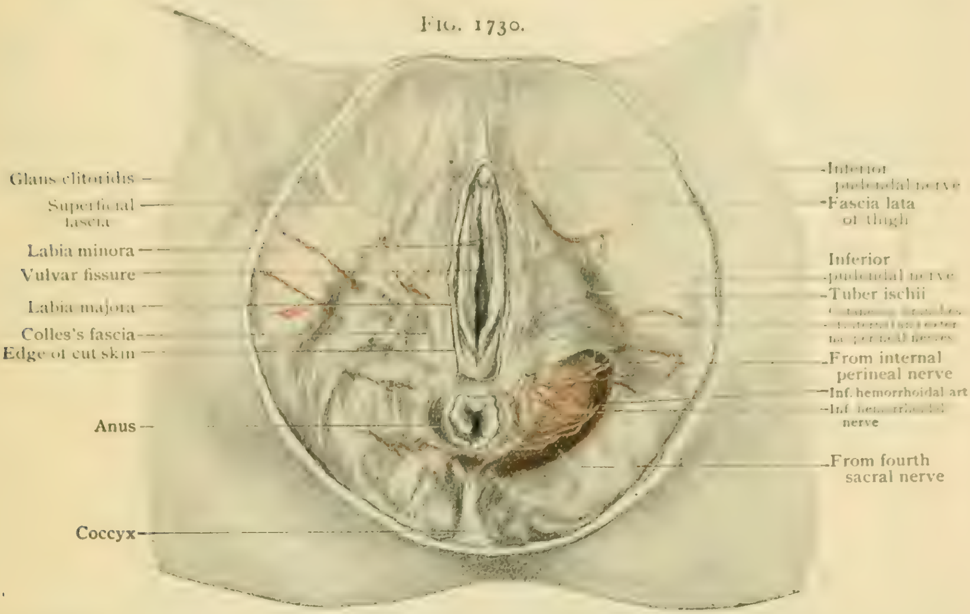
lower part of a triangular fibro-muscular mass, the *perineal body*, that divides the vagina from the rectum and anal canal and contains the perineal centre with the converging fibres of the external sphincter, transverse perineal, and bulbo-cavernosus (sphincter vaginæ) muscles.

Apart from its somewhat greater breadth and more generous layer of fat, the rectal triangle presents no special features and contains the same structures as in the male. The superficial fascia, prolonged from the thighs and buttocks and usually laden with fat, closes in the ischio-rectal fossæ and is directly continuous with the fatty areolar tissue filling these spaces. The internal pudic vessels and pudic nerve occupy the fascial (Alcock's) canal on the outer wall of the ischio-rectal fossa and give off the inferior hemorrhoidal branches distributed to the skin and muscles surrounding the anal canal.

Over the urogenital triangle the superficial fascia is divisible into two distinct layers, a superficial and a deep. The former, loaded with fat, is continuous above and at the sides with the corresponding stratum on the abdomen and the thighs, and behind with the superficial fascia covering the rectal triangle. The deep layer, or Colles's fascia, is devoid of fat and membranous in character. Behind, where it turns

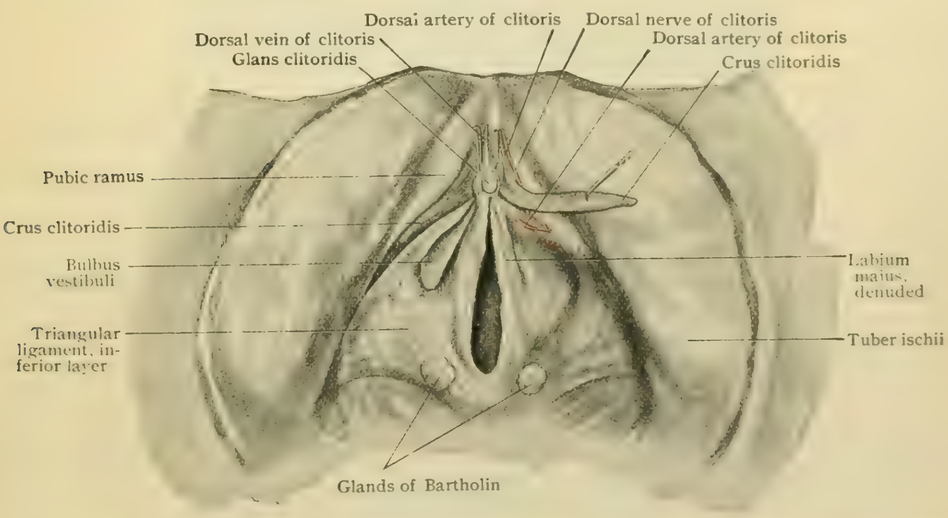
over the transverse perineal muscles, it blends with the posterior border of the triangular ligament along the perineal shelf; laterally, it is attached to the ischial and pubic rami; and in front it is prolonged over the labia majora to become continuous with the corresponding fascia (Scarpa's) over the abdomen.

FIG. 1730.



Superficial layer of superficial fascia has been removed from urogenital triangle; Colles's fascia and cutaneous nerves and vessels exposed.

FIG. 1731.



Dissection exposing bulbus vestibuli, Bartholin's glands and inferior layer of triangular ligament after removal of overlying structures; left crus clitoridis displaced.

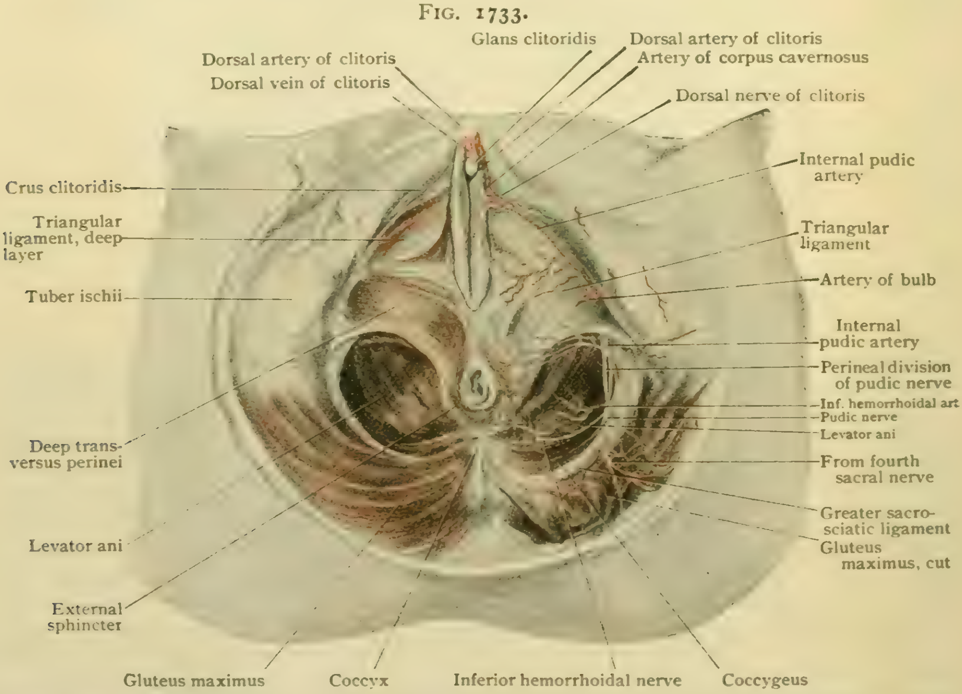
The fascia of Colles forms the lower boundary of the *superficial perineal interspace*, a triangular pocket limited above by the inferior layer of the triangular ligament and behind by the fusion of the latter with Colles's fascia. In addition to the superficial perineal vessels and nerves, the long pudendal nerves, the transverse peri-

neal muscles, and the glands of Bartholin, this space contains the crura of the clitoris, the vestibular bulb and their associated muscles (ischio- and bulbo-cavernosus).

FIG. 1732.

Deep layer of superficial fascia (Colles's fascia) removed, exposing structures within superficial interspace.

FIG. 1733.



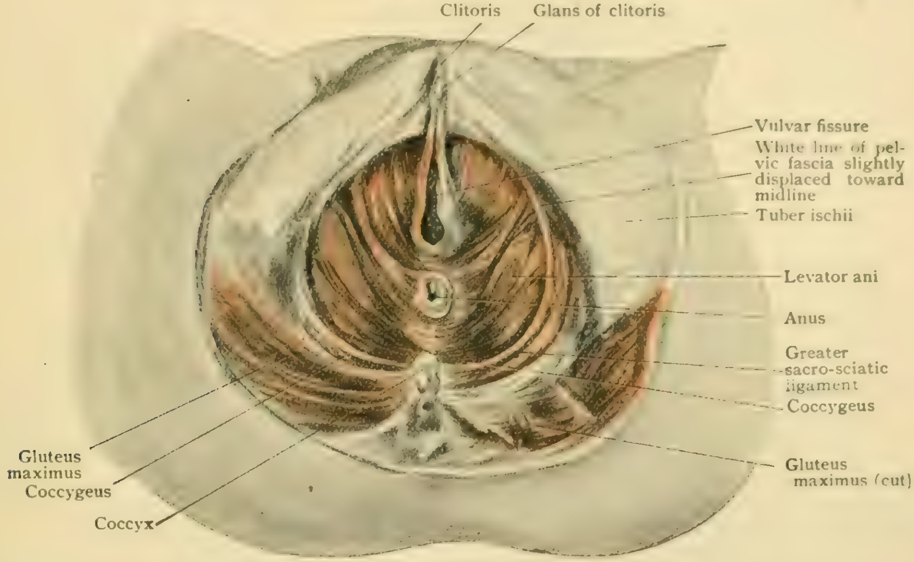
Deeper dissection of perineum; inferior layer of triangular ligament has been removed, exposing deep perineal interspace; ischio-rectal fossa partially cleaned out.

Owing to the diminutive size of the crura clitoridis, the ischio-cavernosus muscles are correspondingly small, but otherwise agree with those in the male.

The presence of the urogenital cleft prevents the fusion not only of the vestibular hemibulbs (the homologues of the halves of the corpus spongiosum), but also of the bulbo-cavernosus muscles, which, therefore, are present in the female as separate bands that encircle the vestibule.

The bulbo-cavernosus muscle, often called the *sphincter vaginæ*, arises from the perineal centre, blending with the fibres of the external sphincter and the transverse perineal muscles, and divides into a median and a lateral portion as it passes forward. The lateral and more superficial strand encircles the vagina, crosses the crus to gain the dorsum clitoridis, and ends, with the tendon of the opposite muscle, by blending with the fibrous sheath of the clitoris. The median and deeper portion of the muscle (the *compressor bulbi* of Holl) partly covers the gland of Bartholin and the vestibular bulb, and in front unites with the corresponding strand of the opposite side in a

FIG. 1734.



Deep dissection of perineum, exposing muscles of pelvic floor.

delicate tendinous expansion that passes beneath the body of the clitoris and is attached to the crura.

Between the inferior and superior layers of the triangular ligament is included the *deep perineal interspace*. In addition to the continuations of the internal pudic vessels and pudic nerves, this interfascial space is occupied by a thin and imperfect muscular sheet that corresponds with the compressor urethræ. The posterior part of this sheet is differentiated, with variable distinctness, into the deep transverse perineal muscles which, arising from the ischial tuberosities, pass behind the vagina to the perineal centre. The remaining part of the sheet, collectively much less developed than the sphincter-like compressor urethræ in the male, is continued forward from the perineal centre as a thin stratum that closely encircles the vagina, and in front either surrounds the urethra or passes in front of the urethra in the interval between the latter and the transverse ligament (Kalischer). In recognition of its relations to both the vaginal and urethral canals, this muscular sheet has been appropriately called the *urogenital sphincter*.

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